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U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation Programs

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RADIOLOGICAL QUALITY OF THE ENVIRONMENT IN THE UNITED STATES, 1977

SEPTEMBER 1977

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Kurt L. Feldmann, editor

Preface

The Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (EPA) has a primary responsibility to establish radiation protection guidance and to interpret existing guides for Federal agencies. This responsibility was transferred to the Administrator of EPA from the Federal Radiation Council which was abolished by Reorganization Plan No. 3 of 1970. One of ORP's mandates in carrying out this responsibility is to monitor and assess the impact on public health and the environment of radiation from all sources in the United States, both ionizing and nonionizing. Therefore, ORP is continuing a radiological dose assessment program to determine the status of radiation data nationwide, to analyze these data in terms of individual and population doses, and to provide guidance for improving radiation data. In addition, this program will provide information to guide the direction of ORP by the analysis of radiation trends, identification of radiation problems, and support for establishing radiation protection guidance. The general approach in this program is to make maximum use of available data reported by other Federal agencies, States and nuclear facilities.

This report is part of ORP's dose assessment program for evaluating the radiological quality of the environment. Special emphasis was placed on acquiring and summarizing the most recent dose data available. For some source categories, dose information was available for calendar year 1976, for others the most recent data go back to the early 1970's. No effort was made to calculate or extrapolate from existing data to supply missing dose information. Instead, the concern was for the availability of data and what the existing data provide for individual and population dose information. However, gaps in data coverage and areas of inadequate data coverage are identified when found.

It is realized that the reported data are probably not all inclusive. If the reader knows of other information on radiation source categories that has not been included or which has not been given adequate coverage, we would appreciate having this information brought to our attention for future reports.

W. D. Rowe, Ph.D.
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Chapter 1 - Introduction, Summary, and Conclusions

Background

Numerous studies have been conducted in the past by the Environmental Protection Agency (EPA) and other agencies to evaluate the impact of individual radiation sources. This report represents a systematic effort to evaluate the impact from all sources of radiation, both ionizing and nonionizing. Such an evaluation requires the assembling of a broad data base on radiation exposures, a responsibility unique to EPA. This effort in determining the quality of the radiological environment is one part of the Office of Radiation Program's (ORP) overall Dose Assessment Program.

Objective

This report is intended to fulfill ORP's responsibility for determining individual and total United States population doses from all source categories of radiation. In addition, this information will provide guidance for direction of programs in ORP by analysis of radiation trends, identification of radiation problems, and support for establishing standards.

Approach

An effort was made in this report to identify source categories of radiation. The identified sources have been considered in two general categories; (1) ionizing radiation, and (2) nonionizing radiation. In the ionizing radiation category, sources were further grouped under the headings of ambient environmental radiation, technologically enhanced natural radiation, fallout, uranium fuel cycle, federal facilities, radiopharmaceuticals, medical, occupational-industrial, and consumer products. The nonionizing radiation category is mainly concerned with the environmental measurement of sources.

Literature searches were conducted for each of these categories and the data organized to provide the following information:

1. General information about each source category and the availability of data.
2. Data base description (includes who reports data to whom, under what authority, and what data are being reported).
3. Status of data base analyses (to indicate what has been done with the data).
4. A summary of dose data for each source category.
5. Comparison of actual dose data reported with estimates from previous publications.
6. Discussion, evaluation of the adequacy of the data base and needed improvements, and conclusions.

Data acquisition

It was considered that the most cost-effective way for EPA to acquire the necessary data for the preparation of this report on the radiological quality of the environment was to use the available data in the literature as reported by government and nongovernment agencies. It is recognized that much of these data are indirectly related to the interests of EPA as far as population dose and dose assessment are concerned. Nevertheless, in order to determine the need for acquiring additional data by ORP, it was considered necessary first to review and evaluate the available data and secondly, identify the gaps as areas of concern for future investigation. At the same time, source categories were defined for which additional data acquisition was considered to be unnecessary because of the relatively small dose contribution from that category.

Special effort was made in this report to acquire data supported by direct measurements in contrast to estimates made by extrapolations involving numerous assumptions. Most dose information falls in the latter category due to the difficulty or cost of direct measurements. Therefore, most of the data available represent the product of several calculations involving an understanding of the source term and the interaction of that source term with the environment and man.

Data validation

Although it is cost effective for ORP to use data provided by others, there must also be concern for the quality of that data. Consequently, ORP supports data validation activities on a continuing basis, and encourages radiation laboratories to participate in a national quality assurance program. EPA operates such a program for radiation measurements at its Environmental Monitoring and Support Laboratory in Las Vegas, Nevada. This laboratory provides standard radionuclide sources, standard reference materials, and cross-check media for intercomparison measurements with any laboratory desiring to participate.

In addition, EPA conducts special field studies at nuclear facilities or other radiation sources in cooperation with government and non-government agencies. These studies are designed to characterize radiation sources and environmental effects as well as to validate calculated doses and dose models. The use of such models for calculation of doses represents the third activity for data validation. Direct measurements are used to validate the values obtained from models.

Scope

This report is intended to include data as current as possible. However, for some categories, the only available data are for the early 1970's. Because of the time spread of available data, the latest data available are compiled for each source, regardless of the year for which they were determined. Therefore, this report and those of future years will represent a compilation of the latest data available at the time of preparation.

Sources of information

The information for this report was primarily obtained from published reports such as professional society journals, symposium proceedings, and other technical reports. The EPA regional offices were instrumental in obtaining reports of State monitoring activities. Operating and environmental surveillance reports from nuclear power reactors were obtained from the Nuclear Regulatory Commission (NRC). Data for Energy Research and Development Administration (ERDA) facilities were taken from the contractors' annual environmental surveillance reports. Medical x-ray and consumer product information was taken from reports of the Food and Drug Administration's Bureau of Radiological Health.

Environmental Radiation Ambient Monitoring System (ERAMS) data

In addition to the radiation data provided by other agencies, EPA obtains ambient monitoring data from its own national networks. This program is conducted by the Eastern Environmental Radiation Facility (EERF) in Montgomery, Alabama, and involves the analyses of samples of air, milk, and water. The data from these analyses are issued quarterly in an environmental radiation data report. A comprehensive analysis of past ERAMS data is being carried out. A brief summary of that analysis is given in chapter 2 to complete that section on ambient ionizing radiation.

Summary

The purpose of this report is to summarize the individual and population doses in the United States resulting from each category of radiation source and to assess these data. When the literature on radiation sources was searched for information, it became readily apparent that an immense amount of data had been published during the past 15 years. It was therefore considered necessary, first to organize the sources into the categories described in this report, and secondly, to summarize, examine and interpret the data with respect to these categories. In doing so, it was also necessary to assume that the data extracted from the literature were valid. Because of the many different purposes for which environmental data were generated, the results are not only expressed in different units, but they were accumulated over different time periods and frequently were obtained without quality control. For this reason, many tables of data carry detailed notes and annotations. Readers are cautioned that before data in this report are used for their purposes, they should read the text and the notes to assure proper interpretation.

The individual and population dose data resulting from the various categories of radiation sources discussed in this report are summarized in table 1-1. The information in this table is divided according to whether the primary mode of exposure is external or internal. Exposure to direct radiation from radionuclides in the ground, water, buildings, and air around us, or from radiation-producing machines, such as x-ray equipment and particle accelerators, is considered to be external exposure. Exposures of this type usually result in a radiation dose to the whole body of the person exposed. In contrast, internal exposures occur when radioactive materials are inhaled, ingested, or absorbed through the skin. Internal exposures result in radiation doses to specific organs of the body, such as the lung, gastrointestinal tract, or bones.

It is evident from this table that there are radiation sources for which data are not available. Consequently, the discussion and comments that result are based upon the data which were available at the time of writing. Also, it is worth noting that although population doses from the different source categories, in general, can be added together to gain a perspective of overall impact, it does not necessarily follow that individual doses can be added together because an individual in one population group generally does not receive the radiation dose common to another population group. For this reason, the data in table 1-1 only show totals for population doses in the various source categories.

Dose to United States population

Based upon the limited data in table 1-1, it is apparent that the source category of highest population dose is the external dose from cosmic radiation. An overall population dose from ambient ionizing

Table 1-1. Summary of dose data from all sources, United States

Source	External: Individual dose (mrem/y)	External: Population dose (person-rem/y)	Internal: Individual dose (mrem/y)	Internal: Population dose (person-rem/y)
Ambient ionizing radiation	-	-	-	-
Cosmic radiation	41-45	9.7×10^6	-	-
Ionizing component	28-35	9.2×10^6	-	-
Neutron component	0.33-6.8	4.9×10^5	-	-
Worldwide radioactivity				
Tritium	-	-	0.04	9.2×10^3
Carbon-14	-	-	1	-
Krypton-85	[a].035*	-	-	-
Terrestrial radiation	30-95	-	18-25	-
Potassium-40	17	-	16	-
Tritium	-	-	4×10^{-3}	-
Carbon-14	-	-	1	-
Rubidium-87	-	-	0.6	-
Uranium-238 series	13	-	2-6*	-
Thorium-232 series	25	-	7*	
Technologically enhanced natural radiation	-	-	-	2.73×10^6
Ore mining and milling	-	-	100,000*	-
Inactive uranium mill tailings piles	-	-	[b]140-14000	[c]2.5-70000
Phosphate mining & processing (occupational)	10-300*	-	[b]6,000*	-
Fertilizer	1.7*	-	-	-
Thorium mining and milling	-	-	-	-
Radon in potable water supplies	-	-	[b]4,000([d]1,250)*	-
Radon in natural gas	-	-	[b]15-54	2.73×10^6
Radon in liquefied petroleum gas	-	-	1-4	30000
Radon in "health" mines	-	-	-	-
Radon daughter exposure in natural caves	-	-	-	-
Radon and geothermal energy production	-	-	-	-
Radioactivity in construction material	-	-	-	-
Airplane travel				
Jet (cosmic), per trip over Atlantic	2.6(500-crew)*	-	-	-
SST (cosmic), per trip over Atlantic	2.0(1,000-crew)*	-	-	-
Coal-fired electric generating station	-	-	5-70*	$0.12\text{-}2 \times 10^6$*
Oil-fired electric generating station	-	-	0.04*	15*

Table 1-1 cont. Summary of dose data from all sources, United States

Source	External		Internal	
	Individual dose (mrem/y)	Population dose (person-rem/y)	Individual dose (mrem/y)	Population dose (person-rem/y)
Fallout	$^{e}\sim 2$	-	-	-
Uranium fuel cycle	-	2014	-	-
Mining and milling	-	-	$^{f}4.5\times10^{-2}$	2.5
Fuel enrichment	$^{g}<0.1$	<0.1	$^{h}0.3$	$^{i}0.64$
Fuel fabrication	-	-	$^{j}2\times10^{-4}$	$^{j}0.66$
Power reactors BWR	$^{k}76$ max	$^{m}1564$	-	-
PWR	$^{k}4$ max	$^{m}21$	-	-
Research reactors	-	-	-	-
Transportation - Nuclear power industry	-	^{n} 100-9600	-	-
Radioisotopes	-	$^{n}<170$		-
Reprocessing and spent fuel storage	$^{p}6$	$^{p}23$	$^{p}14-257$	-
Radioactive waste disposal	-	-	-	-
Federal Facilities	-	$^{q}480$	-	-
ERDA	$^{k}<0.1-258$	<1-180	-	-
Department of Defense	<0.01	-	-	-
Accelerators	$^{k}0.04-4$	0.4-65	-	-
Radiopharmaceuticals	-	$^{r}<0.1$	-	$^{s}3.3\times10^{6}$
Medical radiation				
X radiation	$^{t}103$	14.8×10^{6}	-	-
Cardiac pacemakers	-	-	<5000	-
Occupational and industrial radiation				
BWR	$^{u}1230$	-	-	-
PWR	$^{u}1080$	-	-	-
All occupations	$^{v}0.80$	28,400	-	-

Table 1-1 cont. Summary of dose data from all sources, United States

Source	External		Internal	
	Individual dose (mrem/y)	Population dose (person-rem/y)	Individual dose (mrem/y)	Population dose (person-rem/y)
Consumer products	-	-	-	-
Timepieces	[x]<0.5*	[y]$\sim$6100	-	-
Smoke detectors	[z]0.007*	0.001*	-	-
Artificial teeth	-	-	[aa]140-1390*	-
TV	[bb]0.025-0.043	-	-	-

	Individual exposure ($\mu W/cm^2$)
Nonionizing electromagnetic radiation	
Broadcast towers and airport radars	10
All sources	0.1-1

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[a] Maximum individual dose to skin surface
[b] Trachea-bronchial dose
[c] Lung-rem/y
[d] Stomach dose
[e] 50-year dose commitment divided by 50
[f] Average individual lung dose within 80 km
[g] Maximum potential exposure per facility
[h] Maximum potential exposure
[i] Cumulative exposure per facility within 80 km radius
[j] Estimated bone dose within 80 km
[k] Fence line boundary dose
[m] Within a radius of 80 km
[n] Estimated for the year 1973
[p] For NFS Reprocessing Plant, West Valley, N.Y.
[q] 1965 data
[r] Based upon data from 5 institutions
[s] Estimated 1980 dose
[t] Estimated mean active bone marrow dose to adults-mrad/y
[u] Average occupational exposure/y
[v] Average exposure for all occupations & 3.7 radiation workers/1000 persons in United States
[x] From digital watches
[y] From timepieces containing tritium or radium-activated dials
[z] Estimated
[aa] Dose to the superficial layer of tissue
[bb] 5 cm from TV set; units of mR/h
- No dose data available
*Indicates new or revised information

radiation is not given because population doses from the worldwide radiation and terrestrial radiation components is not available. Judging from the figures given for individual doses from these three categories, it would appear that the population dose from terrestrial radiation might be equal to or greater than the 10 million person-rem dose from cosmic radiation. The second largest source of population dose is from medical and dental radiology. This dose was estimated to be about 14.8 million person-rem to the U.S. population.

The third largest category of population dose for which data are available is from the use of radiopharmaceuticals for medical radiation purposes, which is estimated to contribute an internal dose of approximately 3 million person-rem per year to the population dose. The fourth largest category of dose is estimated to be from technologically enhanced natural radiation which contributes approximately 3 million person-rem per year to the population dose. Finally, it is of interest to note that all the population doses from all the other source categories for which data are available are less than 0.1 percent of the total population dose.

It is important to mention that the population dose values noted here are based upon the data available to us at this time. It is possible that these values, and thus the relative contributions of population dose from the source categories considered, could change in the future as more information on this subject becomes available.

Dose to individuals

For individuals, the largest dose is derived from technologically enhanced natural radiation. It contributes internal doses as high or higher than 100,000 mrem/y to the tracheobronchial surface tissue of the lung as a result of the inhalation of radon daughter products from uranium mill tailings.

The second category contributing to a high individual dose is medical radiation which contributes internal doses as high as 5000 mrem/y from radioactive cardiac pacemakers. Artificial teeth were found to contribute a local tissue dose as high as 1390 mrem/y to the individual due to their uranium content. Occupational and industrial operations were found to contribute a dose of 1230 mrem/y to the individual worker, essentially to maintenance personnel working around boiling water nuclear power reactors. Finally, the next largest dose is that which might be received by individuals at the boundary of federal facilities, 258 mrem/y.

As has been mentioned above, the relative contributions from each of the source categories are subject to revision as may be required by new data.

Evaluation of the data base

It is apparent from table 1-1 that most of the results on individual and population doses are based upon calculations which lead to estimated data. It is customary to prefer measured data to calculated data because of the assumption that they are more accurate and reliable. However, frequently, in order to arrive at certain dose information, it is sometimes impractical or impossible to perform dose measurements. Consequently, under these circumstances, the only possible or cost-effective way of determining the dose to an individual or a population is through dose model computation. This type of calculation generally involves experience and judgment to arrive at order of magnitude estimates which are considered to be satisfactory for dose assessment. For example, it is impossible to measure the dose to an individual from the potassium-40 in the human body. However, data on the potassium-40 concentration in the body, energies and types of radiations, half-life of the radionuclide and mass of the body are available and can be used to compute the dose. Such doses may be considered to be reliable and conservative estimates with the understanding that, in all probability, the values for the actual doses are appreciably smaller than the estimated values.

In determining individual doses, it is important to appreciate the fact that these doses are for specific categories which are additive only if it is reasonable to expect that the same individuals would be exposed to the sources in these categories. For example, in general, the individual dose from uranium mining and milling should not be added to other source categories in the uranium fuel cycle because different individuals are involved in these exposures.

Finally, after searching the literature for individual and population dose values and studying the manner in which many of these values were determined, it became evident that frequently the number of significant figures representing the data could not be justified. For this reason, the data in table 1-1 are considered valid only to about 2 significant figures in spite of the fact that more figures are given in the literature and used in this report.

It is also evident from table 1-1 that many gaps appear in the data. This is due to the fact that while some of the information published is oriented towards individual dose, most data are expressed in terms of concentrations of isotopes in various environmental media. For example, data concerned with phosphate mining and processing operations report that occupational personnel in the industry are exposed to uranium decay chain products which are present in ore with a concentration of 4 to 10 picocuries per gram. It is not possible to obtain an estimate of population dose from these data without considerable supplementary knowledge. For this reason, no dose data are reported for this category. It is hoped that these data gaps will be filled in future reports.

In addition to this evaluation of the data base, each chapter in the report contains a more detailed evaluation of the data base pertinent to that chapter.

Conclusions

1. On the basis of the population dose data in this report, the four major source categories of radiation dose to the United States population are ambient ionizing radiation, medical and dental radiation, the application of radiopharmaceuticals in medicine, and technologically enhanced natural radiation. The reason for these relatively high dose values is due to the large populations that are exposed to the sources in these categories.

2. On an individual basis, the largest sources of dose are from technologically enhanced natural radiation, medical radiation, ambient ionizing radiation, consumer products, occupational and industrial operations and federal facilities. The source responsible for high individual doses in the category of technologically enhanced natural radiation is uranium mill tailings that had been used in the construction of residences. The risk to an individual from the dose received from the use of a cardiac pacemaker must be weighed against the benefit derived from this device. It is quite conceivable that if dose from other sources in this category were available, additional high individual doses would be observed.

3. There are many gaps in the dose data of this report. For this reason, the resulting observations and comments are necessarily restricted to this data base. There is a need to greatly improve the data base for dose assessment in the United States.

Chapter 2 - Ambient Ionizing Radiation

The ionizing radiation dose received from the ambient environment is considered to be composed of three parts: 1. cosmic radiation, 2. worldwide radioactivity, and 3. terrestrial radiation.

Cosmic Radiation

Man's usual environment, the surface of the earth, is continually being bombarded by cosmic radiation. This radiation by definition originates in intersteller space or in the cosmos. However, from time to time the "cosmic" component of our natural radiation exposure is increased by injections of high-energy radiation from our own sun.

The majority of the work reported, by necessity, has been the characterization of cosmic radiation and the measurement of the flux and flux spectra. This work in the United States has been carried out directly by federal agencies, such as the U.S. Atomic Energy Commission, the U.S. Air Force and the U.S. Department of Commerce (National Bureau of Standards); by laboratories such as the Health and Safety Laboratory, Argonne National Laboratory, Pacific Northwest Laboratories, Holifield National Laboratory (Oak Ridge); and by universities such as the University of California (Lawrence Livermore Laboratory and Lawrence Berkeley Laboratory), the California Institute of Technology, and other groups such as the National Academy of Sciences.

The research findings have been reported in all forms. Special committee reports, annual reports, project reports, symposium proceedings, and journals. A partial list of journals include Science, Journal of Geographical Research, Physics Review, International Physics Review, Nuclear Instrumentation & Methods, Review of Modern Physics, Journal of Applied Physics, Nucleonics, and Health Physics.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports of the twentieth, twenty-first, and twenty-second sessions contained in the 1966 and 1969 publications were used to produce the 1972 report. These reports provide excellent literature reviews and state-of-the-art references.

Reports of the dose equivalence (DE) in the literature vary. Even recent dose rate measurements differed, as shown by Oakley *(2.1)*, from 30 to 40 percent and by 30 percent in UNSCEAR (1972) *(2.2)*. Also, much of the literature data is presented without any dose equivalence or quality factor (QF) information and one must infer that a certain QF was used. In some instances, the value after a QF is applied, seems to be reported consistently as mrad instead of mrem.

Variables measured

Actual measurements of the incident radiation intensities have been made for about 40 years; but research work has shown that the present intensities have not changed appreciably for the last 40,000 years, and probably this time is much longer *(2.3)*. In fact, the levels may have remained fairly constant for 10^8 years with maximum increases of 10 percent occurring during the reversal of the earth's magnetic field; the most recent field reversal occurring 700,000 years ago *(2.1)*. There are two components to cosmic radiation, the ionizing component and the neutron component. There are also four variables which affect these two components that have been described. These are variation in time, latitude, barometric pressure, and altitude.

Time

Changes with time over long and short periods have been observed and reported. There is what appears to be a fluctuation of a few percent change over an 11-year period which is in phase with sun spot activity and a large 7-fold increase for a few hours has been noted *(2.3)*; but in general, the integration of the exposure at the earth's surface over a year's period makes the total contribution of such large events small.

Latitude

The latitude effect was the first variable to be described and the overall effect causes about a 2 percent variation throughout the contiguous United States latitudes. The latitude variation observed in the neutron flux is about 15 percent for the United States, but neutrons are a small component of cosmic radiation.

Barometric pressure

The overall variation in barometric pressure has no effect on the long-term estimation of cosmic radiation, but the barometric pressure may vary by 3 percent from day to day. Thus, the barometric pressure variance can represent a source of error in comparing the different values for cosmic radiation that appear in the literature.

Altitude

Because there are many uncertainties in the various measurements made to date, the only variable previously considered by Oakley *(2.1)* was the altitude. The other variables tended to be obscured by the differences between measurement techniques.

Most of the cosmic radiations, upon striking the earth's upper atmosphere, produce secondary radiations. Actually, very few of the primary radiations penetrate as deep as the earth's surface; thus, the secondary radiations are the major source of man's exposure, and flux intensities of the secondary radiation increase with increasing distance from the earth's surface.

Neutron component

The poorest knowledge is about the neutron component since this component is more sensitive to time, latitude, and altitude. At sea level, the flux density is small and difficult to measure. The 1972 UNSCEAR report utilized a fluence to dose conversion factor of 4.95 μrad/h for a flux density of 1 neutron/cm^2/s. This was based on averaging the dose rates to a depth of 15 cm for a slab of tissue; 30 cm thick; the maximum dose rate below 1 cm occurs at 1 cm and is 5.25 μrad/h *(2.2)*.

Oacley, for his work, chose the UNSCEAR (1966) 0.7 mrad/y with a quality factor of 8 (QF=8) or 5.6 mrem/y *(2.1)*. The later UNSCEAR (1972) report adopts 0.35 mrad with a QF=6 or 2.1 mrem/y as the average tissue absorbed dose rate at sea level, 40° latitude; but the report cautions that the variations must be borne in mind and that no account is taken of attenuation or buildup due to surrounding structures. Shielding of 50 g/cm^2 can provide a 30 percent reduction in the exposure at sea level *(2.4)*. Also, a recent National Council on Radiation Protection (NCRP) committee report indicates that a QF of 5 should be applied to the neutron component *(2.5)*. The values reported are summarized in table 2-1.

Ionizing component

The ionizing component does not vary greatly at sea level but differences between measurements exist. Oakley *(2.1)* used the average values reported at sea level in the United States (post-1956) and obtained a value of 2.44 ion pairs (I) per cm^3 per second (s) which was equivalent to 4.0 μrem/h or 35.3 mrem/y. The UNSCEAR (1966) value was 29 mrem/y *(2.6)*. The UNSCEAR (1972) report indicated that the work of one researcher appeared inconsistent and adopted a value of 2.14 I/cm^3/s at normal temperature and pressure (NTP). Assuming that each ion pair in air is equivalent to 33.7 eV, the dose in air/I/cm^3/s would be 1.50 μrad/h; thus, the air dose rate adopted was 28 mrad/y or 3.2 μrad/h *(2.2)*. If the radiation is very penetrating, the absorbed dose index

Table 2-1. Individual external doses from cosmic radiation

Component and reference	Dose (mrad/y)	Dose equivalent (mrem/y)	Quality factor used
Neutron dose at sea level			
UNSCEAR (1966) (*2.6*)	0.7	5.6	8
Upton et al. (*2.1*)	0.38	3.0	8
Watt (*2.1*)		6.8	
O'Brien & McLaughlin (*2.1*)		0.33	3
Hajnal et al. (*2.1*)		3.3	
Oakley (*2.1*)	0.7	5.6	8
[40° Lat.] UNSCEAR (1972) (*2.2*)	0.35	2.1	6
[Equatorial] UNSCEAR (1972) (*2.2*)	0.20	1.2	6
NCRP (*2.5*)			5
Ionizing component exposure			
Oakley (*2.1*)	35.3	35.3(2.44 I/cm^3/s)	1
UNSCEAR (1966) (*2.6*)	29	29	
UNSCEAR (1972) (penetrating) (*2.2*)	28	28(2.14 I/cm^3/s)	1
UNSCEAR (1972) (muons) (*2.2*)	28	31	1.1
Combined doses			
Oakley (sea level) (*2.1*)		40.9	
Klement et al. (August - United States) (*2.10*)		45	
[40° Lat.] UNSCEAR (1972)(*2.2*)		30.1	

I = ion pair

rate is unity; but for other cases, 75 percent of the exposure is due to cosmic ray muons, the factor should be 1.1 or 3.5 µrad/h which would be 31 mrad/y. These reported values are also summarized in table 2-1.

Exposure above the earth's surface

New data are constantly being added and compared with previous literature reports. The origin of the primary cosmic rays has still not been determined. Most of the observed radiation is believed to originate in our galaxy and two distinguishing terms have been adopted: galactic cosmic rays and solar cosmic rays.

Man's activities such as space travel and the development of supersonic transports (SST) have increased the interest in the calculation of exposures at locations other than the surface of the earth. For instance, the neutron component contributions to exposure at sea level is small, but it rapidly increases with altitude and reaches a maximum between 10 and 20 km.

The evaluations of exposure related to high altitude SST travel have indicated that the passenger-rem received will be less than in a conventional jet. Although the exposure at the higher altitude is greater, the SST will fly at greater speeds and the trip will take less time in the SST. Thus, an Atlantic crossing by SST is shown to be 2 mrad, while 2.6 mrad has been stated for present day jets *(2.3)*. However, the increased exposure at the higher altitudes may be reflected in the crew exposures. The present jet crew exposure for flying 600 hours is 0.5 rem/y. With SST travel, this would increase to 1 rem/y.

Compared to the galactic cosmic radiation, radiation of solar origin does not contribute significantly to the average dose rate; but during an intense solar flare, dose rates may increase several orders of magnitude *(2.7)*. However, giant flares only last about 10 hours and only occur a few times during each 11-year cycle; thus, if SST aircraft were equipped with radiation detection devices that would alarm when a prescribed radiation action level was reached, the pilot could decrease his altitude until a safe radiation level was reached.

The QF used at the higher altitudes may need to be different. Schaefer, who estimated the 1 rem/y exposure at about 20 km (65,000 feet), used a QF of 8 for the neutron component. His work and others have been reviewed by O'Brien and McLaughlin, who concluded that one can estimate the annual dose-equivalents to passengers and crew; and that they expected to see, "the development of cosmic-ray ionization profiles with altitude for several latitudes, as well as dose and dose-equivalent rate curves" *(2.8)*.

During space travel, persons are exposed to primary cosmic ray particles, the radiation from solar flares, and the intense radiation in the two Van Allen radiation belts. The maximum dose rate inside a 0.7 g/cm^2 shield was reported by Savun et al. to be 22 rad/h (inner belt) and 5.4 rad/h in the outer belt *(2.9)*.

Combined cosmic radiation

The combined cosmic radiation exposure at sea level as presented by Oakley is 4.6 μrem/h or 40.9 mrem/y *(2.1)*. The combined cosmic exposure at sea level, 40° latitude, and NTP as shown by UNSCEAR (1972) is 30.1 mrem/y *(2.2)*. These differences as shown in table 2-1 result primarily because of the use of a different QF.

Other differences such as latitude (Florida to Alaska varies from 30 to 45 mrem/y) and altitude (sea level to 8,000 feet varies from 40 to 200 mrem/y) have been used to produce an average exposure for each county or similar political unit in the United States. This information from Klement, et al. is shown in table 2-2 *(2.10)*. These authors also present estimates of the annual person-rem for years 1960-2000, and for 1970, the value given is 9.2 million person-rem based on United States population of 205 million people *(2.10)*. This is also based on the average of 45 mrem/person in the United States as shown in table 2-2.

The annual passenger-kilometers flown should be approaching 10^{12} (excluding China) since 4.6 x 10^{11} passenger-kilometers were flown in 1970 *(2.2)*. Assuming a speed of 600 km/h, the total is 10^9 passenger-hours each year. The collective dose for subsonic flights for 1970 was reported to be 250,000 person-rads which corresponds to a worldwide population dose of 0.1 mrad/y/person *(2.2)*. This population exposure compared to the surface exposure is insignificant, however, as previously shown, the cosmic exposure received by certain individuals, such as air crew members, could be 10 to 20 times the average surface exposure.

Summary

The data concerning ambient ionizing radiation indicate values which represent the best conservative estimates for the whole body dose resulting from cosmic ionizing radiation and its neutron component at sea level. These values are dependent upon latitude, longitude, and altitude above the surface of the earth and can result in increases by a factor of 10 or 20 as the altitude increases above sea level. This is readily seen in table 2-2 where the annual cosmic radiation dose in Florida at sea level is 30 mrem/y and in Colorado, about 1 mile above sea level, where the annual dose is 120 mrem/y.

Table 2-2. Estimated annual cosmic-ray whole-body doses *(2.10)* (mrem/person)

Political Unit	Average Annual Dose
Alabama	40
Alaska	45
Arizona	60
Arkansas	40
California	40
Colorado	120
Connecticut	40
Delaware	40
Florida	35
Georgia	40
Hawaii	30
Idaho	85
Illinois	45
Indiana	45
Iowa	50
Kansas	50
Kentucky	45
Louisiana	35
Maine	50
Maryland	40
Massachusetts	40
Michigan	50
Minnesota	55
Mississippi	40
Missouri	45
Montana	90
Nebraska	75
Nevada	85
New Hampshire	45
New Jersey	40
New Mexico	105
New York	45
North Carolina	45
North Dakota	60
Ohio	50
Oklahoma	50
Oregon	50
Pennsylvania	45
Rhode Island	40
South Carolina	40
South Dakota	70
Tennessee	45
Texas	45
Utah	115
Vermont	50
Virginia	45
Washington	50
West Virginia	50
Wisconsin	50
Wyoming	130
Canal Zone	30
Guam	35
Puerto Rico	30
Samoa	30
Virgin Islands	30
District of Columbia	40
Total United States	45

Worldwide Radioactivity

Worldwide radioactivity consists of both naturally occurring and manmade radioactivity. The cosmic ray neutrons cause capture reactions in the atmosphere and in the earth's soil and water cover. The nuclides produced in the earth's cover are discussed in the section dealing with terrestrial radiation. The radionuclides produced in the atmosphere are shown in table 2-3. Although table 2-3 summarizes 14 radionuclides, only two of these nuclides are considered to cause any significant exposure: carbon-14 and, to a lesser extent, tritium. Man's surface activities also affect the carbon-14 and tritium concentrations in the atmosphere as well as adding krypton-85. In addition, radon-222 is a component of worldwide radioactivity; but it will be discussed with terrestrial radiation since its precursors are part of the decay chain of the primordial radionuclide uranium-238 found in the earth's crust.

Tritium

Tritium is produced in the atmosphere by the interaction of high-energy cosmic rays with atmospheric nitrogen and oxygen and it occurs naturally in the earth's surface waters. About 90 percent of natural tritium is found in the hydrosphere, 10 percent in the stratosphere and 0.1 percent in the troposphere. The amount of tritium produced has been measured as 0.20 ± 0.05 tritons/cm^2/s, which corresponds to an annual production rate of 1.6 MCi/y and to a steady state inventory of 28 megacuries in the biosphere *(2.2)*.

The inventory of tritium has been increased, however, by nuclear explosions, the contributions from the nuclear power industry and the use of tritium in private industry. Before the advent of nuclear energy, environmental levels of tritium were in equilibrium with the rates of cosmic ray production and decay; but tritium levels are now expected to slowly increase because of the release of this nuclide by power reactors and the reprocessing of spent fuel. Jacobs has estimated that, by the year 2000, a worldwide inventory of waste tritium will be 96 MCi. The tritium would mix throughout the hydrosphere, with the oceans and seas representing the largest reservoirs *(2.11)*.

Figure 2-1 shows the estimated world inventory of tritium in the atmosphere and in surface waters. The dose from worldwide tritium depends on the tritium content in food and water which are dependent on the worldwide inventory. Klement et al. estimated the annual whole body dose to the United States population for the period 1960-2000 (table 2-4) *(2.10)*.

Carbon-14

Carbon, one of the elements essential to all forms of life, is involved in most biological and geochemical processes. The radioisotope carbon-14 is produced in the upper atmosphere by interaction of cosmic

Table 2-3 Cosmic ray produced radioactive nuclides (*2.2*)

Radionuclide	Calculated atmospheric production rate (atoms/cm^{2}-s)	Half-life	Maximum energy of beta radiation (keV)
^{3}H	0.20	12.3 y	18
^{7}Be	8.1x10^{-2}	53 d	Electron capture
^{10}Be	4.5x10^{-2}	2.5x10^{6} y	555
^{14}C	2.5	5,730 y	156
^{22}Na	8.6x10^{-5}	2.6 y	545 (β+)
^{24}Na	3.0x10^{-5}	15.0 h	1,389
^{28}Mg	1.7x10^{-4}	21.2 h	460
^{26}Al	1.4x10^{-4}	7.4x10^{5}y	1,170
^{31}Si	4.4x10^{-4}	2.6 h	1,480
^{32}Si	1.6x10^{-4}	700 y	210
^{32}P	8.1x10^{-4}	14.3 d	1,710
^{33}P	6.8x10^{-4}	25 d	248
^{35}S	1.4x10^{-3}	87 d	167
^{38}S	4.9x10^{-5}	2.9 h	1,100
^{34m}Cl	2.0x10^{-4}	32.0 min	2,480
^{36}Cl	1.1x10^{-3}	3.1x10^{5}y	714
^{38}Cl	2.0x10^{-3}	37.3 min	4,910
^{39}Cl	1.4x10^{-3}	55.5 min	1,910
^{39}Ar	5.6x10^{-3}	270 y	565
^{81}Kr	1.5x10^{-7}	2.1x10^{5}y	Electron capture

Table 2-4. Estimated annual whole-body dose to the United States population from worldwide tritium (*2.10*).

Year	Dose (mrem/person)	Dose to U. S. population (person-rem/y)
1960	0.02	3,100
1970	0.04	9,200
1980	0.03	7,100
1990	0.02	6,700
2000	0.03	8,400

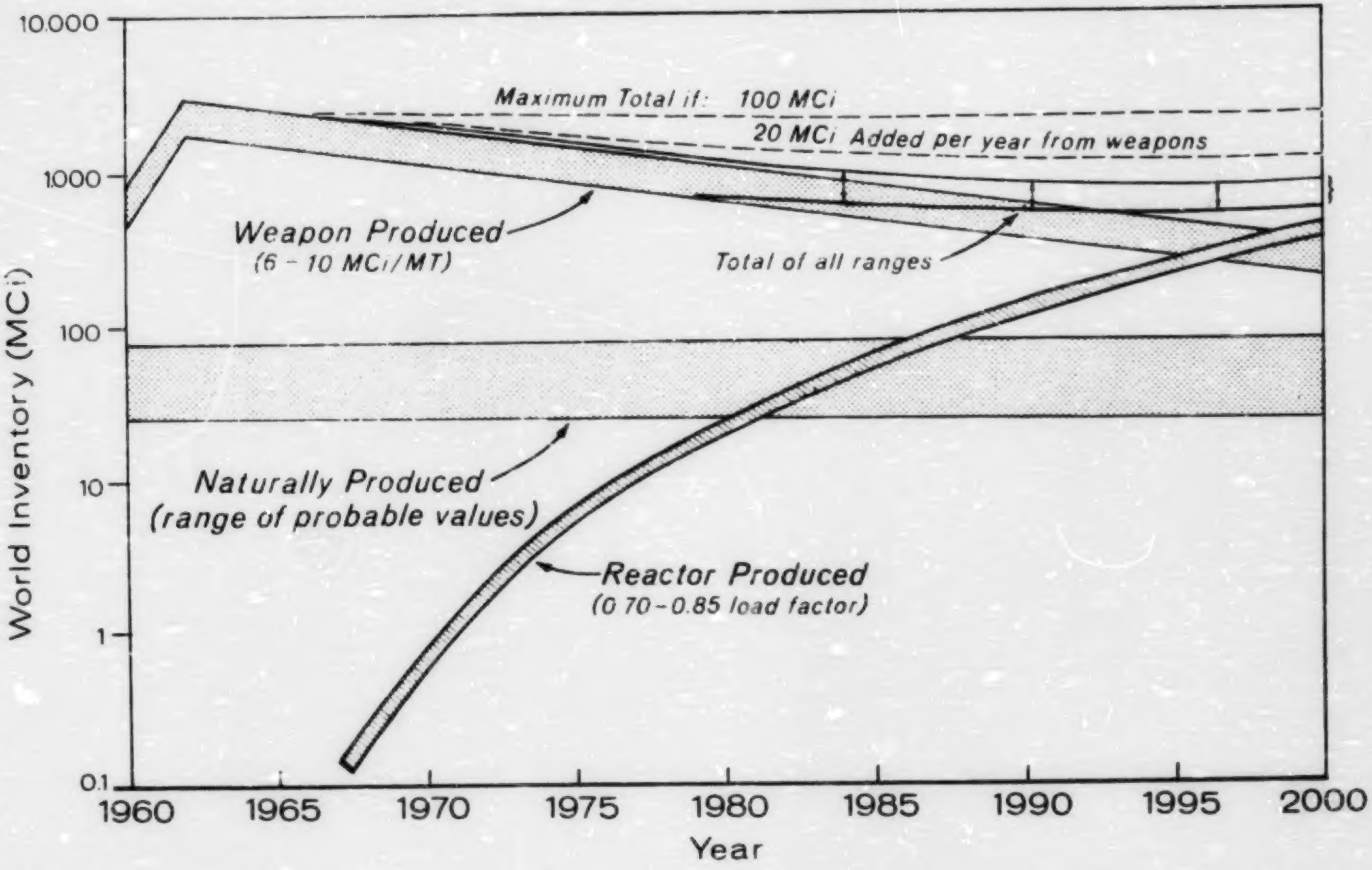

Figure 2-1. Estimated world inventory of tritium in the atmosphere and in surface waters *(2.10)*

ray neutrons with nitrogen. Thus carbon-14 is present in atmospheric carbon dioxide, in the terrestrial biosphere, and in the bicarbonates dissolved in the ocean. UNSCEAR estimates the average dose through the whole body to be 1.02 mrad/y, with the highest dose delivered to fat *(2.2)*.

The natural production rate for carbon-14 is not well known. If the assumed production rate is 2 atoms/s/cm^2, 0.03 MCi/y would be formed providing a steady state inventory of 280 MCi *(2.2)*. The decay rate was estimated to be 1.81 atoms/s/cm^2; and, although this is less than the production rate, the values are actually considered to be in good agreement because of the uncertainties involved *(2.2)*. It has been estimated that nuclear tests have added 6.2 MCi or 5 percent of the steady state amount of carbon-14 to the atmosphere *(2.2)*.

The combustion of carbon-14-free fuel is believed to have caused a decrease in the atmospheric carbon-14 specific activity. The specific activity determined from nineteenth century wood was 6.13 ± 0.03 pCi/g carbon but theoretical reductions (in the absence of nuclear tests) of -3.2 percent in 1950, -5.9 percent in 1969, and -23 percent in 2000 have been calculated *(2.2)*.

Carbon-14 is also produced in nuclear facilities by activation of the fuel, cladding, core structural materials, and coolant. The production rates for carbon-14 as calculated for LWR facilities by Davis *(2.12)* are presented in table 2-5. Current LWR facilities do not have waste treatment systems which remove carbon-14. Therefore, the carbon-14 produced in the fuel will be released at the fuel reprocessing plant and the carbon-14 produced in the coolant will be released at the reactor. The carbon-14 produced in the cladding and core structural materials contribute to the amount of carbon-14 disposed in radioactive waste.

Discharges of carbon-14 from the nuclear power industry require careful consideration since discharges of carbon-14 to the atmosphere can be considered as contributions of a permanent contaminant to the worldwide environment because of the long radioactive half-life of this radionuclide (5,730 years). Carbon-14 is of particular concern since carbon-14 injected into the troposphere becomes part of the carbon cycle, and is constantly moving from inorganic reservoirs (carbon dioxide in the atmosphere and dissolved in water) to the chemical structures of all life forms in the living system and back again.

The maximum annual carbon-14 dose equivalent rates calculated by Fowler et al. *(2.13)* for individuals in the environs of LWR facilities are presented in table 2-6. These estimates are indicated as maximum values since an annual dose equivalent could be received only if an individual were to obtain all of his food at the point of maximum off-site ground level air concentration. Therefore, these dose equivalent rate estimates probably bracket the theoretical upper limit for a conservative generic exposure situation in the vicinity of an LWR facility operating with a decontamination factor of 1 for carbon-14.

Table 2-5. Carbon-14 production rates in LWR facilities (Ci of carbon-14/GW(e)-y) (2.12)

Reactor type	Region of carbon-14 formation	Production Ci/GW(e)-y
BWR	Fuel[a]	17.6
	Coolant	4.7
	Cladding and core structural materials	43.3-60.4
PWR	Fuel[a]	18.8
	Coolant	5.0
	Cladding and core structural materials	30.5-41.6

[a] Based on median amounts of nitrogen present as an impurity in the fuel.

Table 2-6. Maximum annual carbon-14 dose equivalent rates to individuals at LWR facilities in mrem/y (2.13)

Organ	Fuel reprocessing facility	PWR	BWR (with stack)	BWR (without stack)
Total body	1.9	0.48	0.017	0.86
Gonads	.72	.18	.0066	.33

Releases of carbon-14 to the atmosphere are distributed worldwide resulting in a dose commitment to the world population. The majority of the released carbon-14 eventually goes to the deep ocean where it remains with a mean residence time of centuries. However, a portion of the release remains airborne and in the terrestrial biosphere contributing to the environmental dose commitment to man. The worldwide transport of carbon-14 has been estimated by various box models. Using the injections of fossil fuel $^{12}CO_2$ since the beginning of the industrial era (1860) and the inputs of the nuclear fuel cycle $^{14}CO_2$ to the troposphere, the EPA *(2.13)* used a transport model developed by Machta to estimate the carbon-12 and carbon-14 content in the troposphere. The resulting 100-year worldwide environmental dose commitments by year of release were then estimated as shown in table 2-7. By knowing the nuclear power produced in any year, the injections of carbon-14 to the troposphere can be calculated and the conversion factors in table 2-7 can be employed to estimate the environmental dose commitment to the world population for 100 years after release.

Krypton-85

Krypton-85 is a long-lived radioactive isotope of the noble gas krypton and has a half life of about 10.8 years. It is artificially produced mainly by nuclear fission in nuclear reactors. Very little of the krypton-85 formed in reactor operations is released to the atmosphere at the reactor site, but is released at nuclear fuel reprocessing plants. Krypton-85 in minor quantities is produced in nuclear detonations, and it also occurs naturally, primarily from the neutron capture of stable krypton-84 as well as spontaneous fission and neutron-induced fission of uranium.

Krypton-85 is dispersed throughout the atmosphere as there are no significant sinks for removal from the environment. Therefore, the rate of removal is governed by the radiological half-life of 10.8 years. Telegadas and Ferber *(2.14)* have made estimates of the world atmospheric inventory based on measurements and dispersion models to be 53 ± 5 MCi at the end of 1973. Previous estimates of concentrations or inventory appear to be high because the projections of installed nuclear reactors is less than previously estimated and commercial fuel reprocessing in the United States has been temporarily suspended.

Figure 2-2 shows the measured krypton-85 concentrations as made by EPA's Office of Radiation Programs from 1962 to 1976 with the 1976 concentration being around 17 pCi/m^3. Bernhardt et al. *(2.15)* have summarized the population dose resulting from continuous exposure to krypton-85. Based on the 1976 average of about 17 pCi/m^3, the maximum individual dose to the skin surface would be about 0.035 mrad/y.

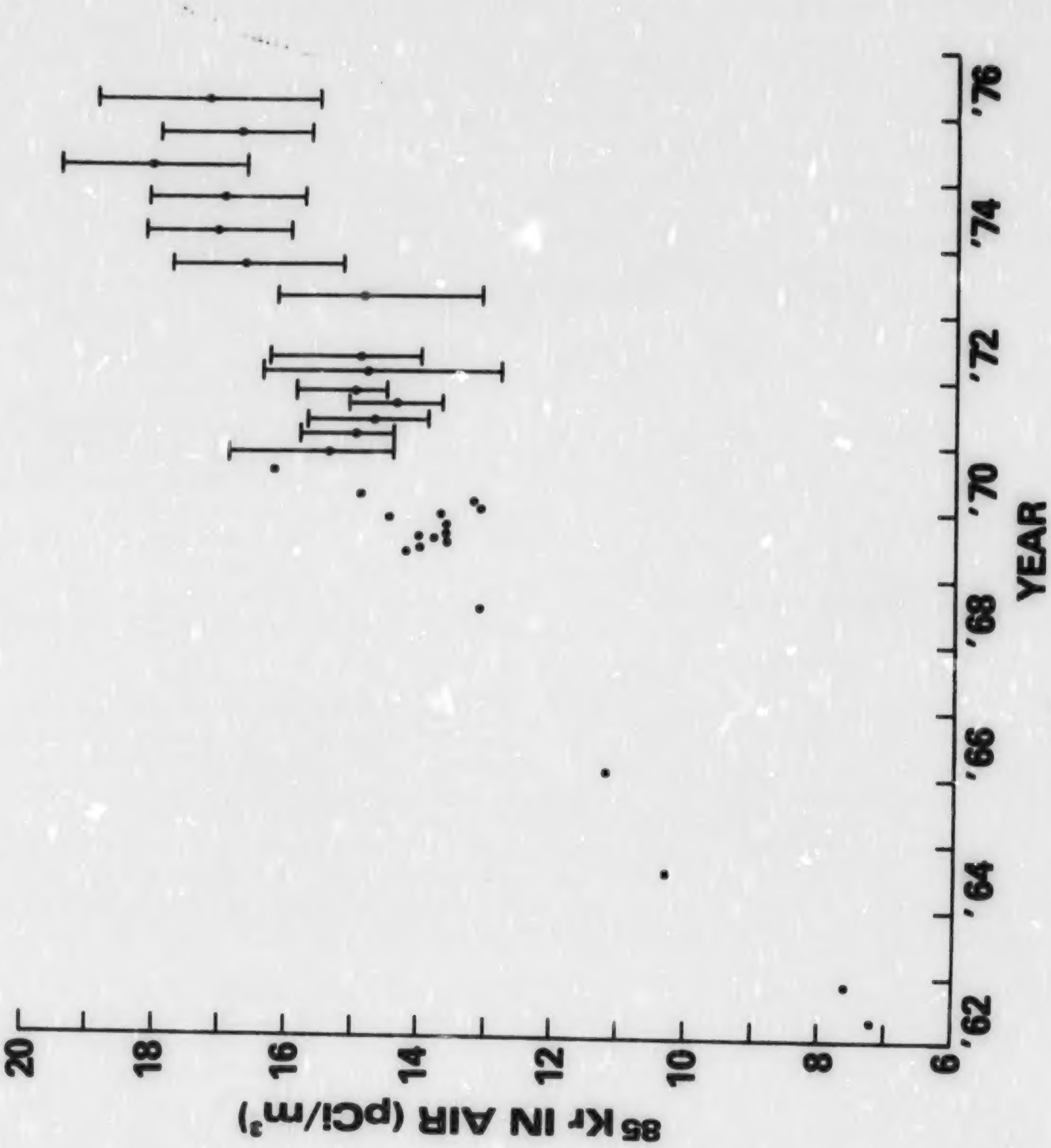

Figure 2-2. Krypton-85 concentrations in air.

Table 2-7. Carbon-14 100-year environmental dose commitment conversion factor for the world population *(2.14)*

Year of release	Carbon-14 100-year environmental dose commitment Conversion factors (person-rem/Ci) Total body[a]	Gonads[b]
1975	45.6	17.4
1976	46.1	17.6
1977	46.6	17.7
1978	47.1	17.9
1979	47.6	18.1
1980	48.0	18.3
1981	48.5	18.5
1982	49.0	18.7
1983	49.5	18.9
1984	50.0	19.1
1985	50.4	19.2

[a] 0.21 mrem/y per pCi carbon-14/g carbon-12 in the total body.

[b] 0.08 mrem/y per pCi carbon-14/g carbon-12 in the gonads.

Terrestrial Radiation

The naturally radioactive nuclides in man's environment produce exposure by both direct external gamma irradiation and by internal irradiation after entering the body via ingestion and inhalation. Food and water are the main exposure pathways and inhalation is of secondary importance, except for uranium daughters which are discussed later.

The description of the occurrences in the literature and the type of organizations performing the research are the same as described previously for cosmic radiation. Most of the previously mentioned journals such as Journal of Geophysical Research and Health Physics, contain articles and others such as Science, Nature, and the American Industrial Hygiene Association could be added. Reports of the U.S. Geological Survey probably provide the largest single source of area soil composition. Actually, the initial interest in the natural radioactivity in soils was not to determine the human exposure but to locate possible mineral deposits by using ratios of nuclide abundance. The development of age dating techniques was also an early use of natural radioactivity.

The naturally occurring radionuclides may be classified into two groups. The nuclides that are continually being formed by the interactions of cosmic ray particles and matter, and those nuclides which have been present since the formation of the earth, the primordial radioactive nuclides.

Cosmic ray interactions

The presence of cosmic ray neutrons does cause capture reactions in the earth's soil cover, but the exposure from these nuclides is insignificant *(2.1)*. The three nuclides which would probably be the major contributors are beryllium-7, sodium-22 and sodium-24.

Primordial nuclides

The primordial nuclides can be divided into two groups: those which decay directly to a stable nuclide and those that belong to one of three naturally occurring radioactive series. UNSCEAR *(2.16)* and Lowder and Solon *(2.17)* presented data for about 24 radionuclides which exist or were hypothesized to exist. However, most have long half-lives and low abundances; thus, only potassium-40, and the decay chains of uranium-238 and thorium-232 are believed to cause any significant exposure. Rubidium-87 has also been mentioned since its abundance (table 2-8) is much greater than the other nonseries primordial radionuclides.

The concentration of the primordial nuclides in the soil will be determined by the associated source rock and the subsequent stage of the soil formation process. Igneous rocks generally have more radioactivity than sedimentary rocks and the metamorphic rocks will exhibit concentrations typical for the rock from which they were derived. However, certain sedimentary rocks, shales and phosphate-bearing rocks are highly radioactive *(2.5)*.

Igneous and metamorphic rocks comprise about 90 percent of the earth's crust; but the sedimentary rocks tend to accumulate at the top of the crust, thus, about 75 percent of the earth's surface is covered by sedimentary rocks. In the contiguous United States, the sedimentary rocks, shale, sandstone, or limestone (in a ratio of 3:1:1, respectively), cover 85 percent of the surface *(2.1)*.

The actual environmental exposure produced will depend on the type of rock, the leaching action of water, the porosity of the overburden, the amount of soil or organic material formed on the surface, and the absorption and precipitation of surface deposited radionuclides. Thus, in boggy soils where leaching and humus buildup occur rapidly, the radioactivity concentration is low. It is higher in forests and would be highest, about equal to the corresponding soil-forming rocks, in arid climate soils *(2.4,2.5)*.

Table 2-8. Nonseries primordial radionuclides *(2.2)*

Radionuclide	Abundance in the lithosphere (ppm)	Half-life (years)	Alpha or E^a_{max} (MeV)	Gamma[a] (MeV)
^{40}K	3	1.3×10^{9}	β 1.314(89)	1.460(11)
^{50}V	0.2	$6. \times 10^{15}$	β ? (30)	0.783(30), 1.550(70)
^{87}Rb	75	4.8×10^{10}	β 0.274(100)	
^{115}In	0.1	$.6 \times 10^{14}$	β 0.480(100)	
^{138}La	0.01	1.1×10^{11}	β 0.210(30)	0.810(30), 1.426(70)
^{147}Sm	1	1.1×10^{11}	α 2.230(100)	
^{176}Lu	0.01	2.2×10^{10}	β 0.430(100)	0.088(15), 0.202(85), 0.306(95)

[a] Figures in parentheses indicate yield per disintegration.

Internal irradiation

The principal internal emitters considered are shown in table 2-9. These radionuclides are present in our environment and enter the body with our food and water. Inhalation is of secondary importance except for radon daughters and the immediate areas surrounding some industrial sites, such as uranium mills or uranium mill tailings piles.

Potassium-40

The main naturally occurring source of internal radiation exposure has been stated to be ^{40}K. It enters the body primarily in food stuffs and its concentration varies considerably in different body organs. Whole body counting studies indicate persons under 20 years of age contain 15 percent less potassium than persons over 20 *(2.2)*. The reasons for this are not immediately evident and are probably due to a combination of things since the potassium concentrations in different tissues are given as: muscle, brain, and blood cells, 0.3 percent; blood serum, 0.01 percent; and fat, none. Thus, the average potassium content of the body will depend on body build, and obese persons have a lower ratio of potassium to body weight than lean persons *(2.2)*. Females have more fatty tissue than males and, therefore, exhibit lower g K/kg body weight ratios *(2.1)*. Three isotopes of potassium occur; two isotopes ^{39}K (93.1 percent) and ^{41}K (6.9 percent), are stable. Despite the low abundance of ^{40}K (0.0118 percent), its activity in soil averages an order of magnitude greater than ^{238}U or ^{232}Th *(2.1)*.

Rubidium-87

The isotopic abundance of ^{87}Ru is 27.8 percent and is about 17 ppm in the whole body tissues of bone and gonads. The average gonadal dose is calculated to be 0.3 mrad/y and 0.4 mrad/y to the small tissue inclusions within the bone. Assuming that the ^{87}Ru concentrations in bone marrow is the same as averaged for the whole body, the dose to the bone marrow would be 0.6 mrad/y *(2.2)*.

Uranium and thorium series

There are three natural series or decay chains. Two start with radioisotopes of uranium, ^{238}U and ^{235}U. The third series start with ^{232}Th. These series are shown in tables 2-10 to 2-12. Uranium and thorium are distributed throughout the earth's crust in approximately the same activity concentration. The activity ratio, $^{235}U/^{238}U$, in nature is less than 0.05, and the radon isotope in the ^{235}U chain (^{219}Rn) has a very short half life, resulting in atmospheric activities of its decay products which are about 2,000 times less than those of ^{222}Rn; thus, the ^{235}U chain is not considered to cause any significant environmental exposure.

Table 2-9. Estimated average annual internal radiation doses per person from natural radioactivity in the United States

Radionuclide	Dose to whole body			Dose to endosteal cells		Dose to bone marrow			Dose to gonads	
	(2.1)[a] mrem	(2.2) mrad	(2.10) mrem	(2.2) mrad	(2.10) mrem	(2.1) mrem	(2.2) mrad	(2.10) mrem	(2.1) mrem	(2.2) mrad
^{40}K	16	[b]19	17	6	8	16	15	15	[c]16	19
^{3}H			0.004	0.001	0.004		0.001	0.004		0.001
^{14}C			1.0	0.8	1.6		0.7	1.6		0.7
^{87}Rb		0.6	0.6	0.4	0.4		0.6	0.6		0.3
^{210}Po[d]	2		3.0	4.0	21	2	0.3	3.0	2	0.6
^{220}Rn[e]							0.05			0.003
^{222}Rn[d]			3.0	0.04	3.0		0.08	3.0		0.07
^{226}Ra[d]				1.6	6.1		0.1	0.3		0.02
^{228}Ra[e]				1.9	7		0.1	0.3		0.03
^{238}U[d]				0.8			0.06			0.03
Total	18	21	25	16	47	18	17	24	18	21

[a] Reference number

[b] 17 mrad/y from beta and 2 mrad/y from gamma

[c] Average: 19 mrem/y, male and 13 mrem/y, female.

[d] Uranium-238 series

[e] Thorium-232 series

Table 2-10. Uranium (radium) series *(2.18)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Uranium-238	^{238}U	$4.5x10^{9}$ y	α	4.18(77), 4.13(23)
Thorium-234	^{234}Th	24.1 d	β	0.19(65), 0.10(35)
			γ	0.09(15), 0.06(7), 0.03(7)
Protactinium-234	^{234}Pa	1.18 min.	β	2.31(93), 1.45(6), 0.55(1)
			γ	1.01(2), 0.77(1), 0.04(3)
Uranium-234	^{234}U	$2.50x10^{5}$ y	α	4.77(72), 4.72(28)
			γ	0.05(28)
Thorium-230	^{230}Th	$8.0x10^{4}$ y	α	4.68(76), 4.62(24)
Radium-226	^{226}Ra	1622 y	α	4.78(94), 4.59(6)
			γ	0.19(4)
Radon-222	^{222}Rn	3.82 d	α	5.48(100)
Polonium-218	^{218}Po	3.05 min.	α	6.00(100)
Lead-214	^{214}Pb	26.8 min.	β	1.03(6), 0.66(40), 0.46(50), 0.40(4)
			γ	0.35(44), 0.29(24), 0.24(11), 0.05(2)
Bismuth-214	^{214}Bi	19.7 min.	β	3.18(15), 2.56(4), 1.79(8), 1.33(33), 1.03(22), 0.74(20)
			γ	2.43(2), 2.20(6), 2.12(1), 1.85(3), 1.76(19), 1.73(2), 1.51(3), 1.42(4), 1.38(7), 1.28(2), 1.24(7), 1.16(2), 1.12(20), 0.94(5), 0.81(2), 0.77(7), 0.61(45)
Polonium-214	^{214}Po	$160x10^{-6}$ s	α	7.68(100)
Lead-210	^{210}Pb	19.4 y	β γ	0.06(17), 0.02(83) 0.05(4)
Bismuth-210	^{210}Bi	5.0 d	β	1.16(100)
Polonium-210	^{210}Po	138.4 d	α	5.30(100)
Lead-206	^{206}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

Table 2-11. Thorium series *(2.18)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Thorium-232	^{232}Th	1.41×10^{10} y	α	4.01(76), 3.95(24)
			γ	0.06(24)
Radium-228	^{228}Ra	6.7 y	β	0.05(100)
Actinium-228	^{228}Ac	6.13 h	β	2.18(10), 1.85(9), 1.72(7), 1.13(53), 0.64(8), 0.45(13)
			γ	1.64(13), 1.59(12), 1.10, 1.04, 0.97(18), 0.91(25), 0.46(3), 0.41(2), 0.34(11), 0.23, 0.18(3), 0.13(6), 0.11, 0.10, 0.08
Thorium-228	^{228}Th	1.91 y	α	5.42(72), 5.34(28)
			γ	0.08(2)
Radium-224	^{224}Ra	3.64 d	α	5.68(95), 5.45(5)
			γ	0.24(5)
Radon-220	^{220}Rn	54.5 s	α	6.28(99+)
Polonium-216	^{216}Po	0.158 s	α	6.78(100)
Lead-212	^{212}Pb	10.64 h	β	0.58(14), 0.34(80), 0.16(6)
			γ	0.30(5), 0.24(82), 0.18(1), 0.12(2)
Bismuth-212	^{212}Bi	60.5 min.	α	6.09(10), 6.04(25)
			β	2.25(56), 1.52(4), 0.74(1), 0.63(2)
			γ	0.04(1), with α 2.20(2), 1.81(1), 1.61(3), 1.34(2), 1.04(2), 0.83(8), 0.73(10), with β
Polonium-212[b]	^{212}Po	0.30×10^{-6} s	α	8.78(100)
Thallium-208[c]	^{208}Tl	3.1 min.	β	2.37(2), 1.79(47), 1.52, 1.25
			γ	2.62(100), 0.86(14), 0.76(2), 0.58(83), 0.51(25), 0.28(9), 0.25(2)
Lead-208	^{208}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

[b] Divide given percentage yields by 1.5 to obtain yield in terms of thorium-232.

[c] Divide given percentage yields by 3 to obtain yield in terms of thorium-232.

Table 2-12. Actinium series *(2.19)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Uranium-235	^{235}U	$7.1\text{x}10^{8}$ y	α	4.40(57), 4.37(18), 4.58(8)
			γ	0.18(54), 0.14(11), 0.20(5)
Thorium-231	^{231}Th	25.5 h	β	0.14(45), 0.30(40), 0.22(15)
			γ	0.08(10), 0.03(2)
Protactinium-231	^{231}Pa	$3.25\text{x}10^{4}$ y	α	5.01(24), 5.02(23), 4.95(22)
			γ	0.29(6), 0.03(6)
Actinium-227	^{227}Ac	21.6 y	α	4.95(1.2), 4.86(0.18)
			β	0.043(99+)
			γ	0.070(0.08)
Thorium-227	^{227}Th	18.2 d	α	5.98(24), 6.04(23), 5.76(21)
			γ	0.24(15), 0.31(8), 0.050(8)
Radium-223	^{223}Ra	11.43 d	α	5.71(54), 5.61(26), 5.75(9)
			γ	0.27(10), 0.15(10), 0.33(6)
Radon-219	^{219}Rn	4.0 s	α	6.82(81), 6.55(11), 6.42(8)
			γ	0.27(9), 0.40(5)
Polonium-215	^{215}Po	$1.78\text{x}10^{-3}$ s	α	7.38(100)
Lead-211	^{211}Pb	36.1 min.	β	1.39(88), 0.56(9), 0.29(1.4)
			γ	0.83(3.4), 0.40(3.4), 0.43(1.8)
Bismuth-211	^{211}Bi	2.15 min.	α	6.62(84), 6.28(16)
			γ	0.35(14)
Thallium-207	^{207}Tl	4.79 min.	β	1.44(99.8)
			γ	0.90 (0.16)
Lead-207	^{207}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

Uranium-238

The uranium-238 chain can be divided into four parts: 1. The long-lived isotopes, ^{238}U, which are considered to be in equilibrium in nature, 2. ^{226}Ra, since its concentrations in the environment and man are not necessarily related to its uranium parents, 3. ^{222}Rn and its short-lived daughters (through ^{214}Po), and 4. the long-lived radon daughters, ^{210}Pb, ^{210}Bi, and ^{210}Po. One gram of natural uranium contains 0.33 μCi ^{238}U and 0.015 μCi ^{235}U *(2.2)*.

Man's uranium uptake in his daily diet has been shown to be 1 μg/d *(2.2)*. The uranium in the soil enters plants and then goes directly into man and herbivorous animals and also into man from herbivorous animals. Water can also provide a source of uranium, and values of 0.024 to 200 μg/ℓ in fresh water are reported *(2.2)*. Uranium, as well as thorium and radium, can be present in air, but normally in very small quantities. Thus, inhalation is not considered to be a source of normal exposure except for radon and its daughters. The exposures calculated for uranium are shown in table 2-9.

Thorium-232

Thorium enters man in the same manner as uranium, and experiments performed with plants showed that thorium was readily absorbed by plant roots; however, no intake values appear in the literature *(2.2)*. It also appears that although thorium is readily absorbed, the concentration in the plant's shoots is negligible compared to radium.

Radium

Radium isotopes are present in all soils and will be found in varying equilibrium with its parents. Since uranium and thorium are usually present in about the same activity concentrations, the isotopes of radium, ^{226}Ra and ^{228}Ra, from ^{238}U and ^{232}Th, respectively, will also be present in similar activity concentrations. However, the normal ^{226}Ra concentration may be increased by the addition of phosphate fertilizers.

The average daily uptake of ^{226}Ra in normal background areas is stated to be 1 pCi/g of calcium *(2.2)*.

Radon

Radium-225 decays by alpha emission to its daughter, ^{222}Rn, an inert gas having a half-life of 3.8 days. Similarly, radon-220 is the daughter of ^{224}Ra in the thorium-232 decay chain (table 2-11). These gaseous isotopes can then diffuse from the soil into the atmosphere. The atmospheric concentration of these gases and their daughter products depends on many geological and meteorological factors. Because the daughter products of radon and thoron are electrically charged when formed, they tend to attach themselves to the dust particles normally present in the atmosphere, thus becoming the only significant natural radionuclides leading to widespread exposure through inhalation.

Radon can also reach man through water, and the ingestion of 1 μCi of ^{222}Rn dissolved in water has been indicated to cause a 20 mrad exposure to the stomach *(2.6)*. Another source could be milk, but values should be lower (in Sweden, ^{222}Rn concentrations in milk are 40 times less than in water) *(2.2)*.

Long-lived radon-222 daughters

The average concentration of ^{210}Pb for a location will depend on the ^{222}Rn surface exhalation rate at that point and the global pattern of air circulation. The average ^{210}Pb to ^{210}Po ratio will be 10 in the northern middle latitudes. The concentrations would be 15 and 1.5 Ci/m^3, respectively *(2.2)*. However, ratio values of less than unity can be found in industrial areas. This has been attributed to the release of ^{210}Po during the combustion of coal. The standard man inhales 20 m^3 of air per day; thus, for the "normal" areas, 0.3 pCi ^{210}Pb and 0.03 pCi ^{210}Po would be inhaled.

Cigarette smoking causes an additional uptake of lead-210 and polonium-210 as both are present in tobacco; ^{210}Po is more abundant because it is highly volatile. One pack of cigarettes per day causes a daily intake of 0.3-0.8 pCi ^{210}Pb and 0.4 to 1.4 pCi ^{210}Po *(2.2)*. If a lung to blood transfer coefficient of 0.3 is used, 0.2 and 0.3 pCi/d would be the resultant uptake.

The daily intake from the western diet of milk, bread, meat, and vegetables is 1-10 pCi/d ^{210}Pb with a ^{210}Pb/^{210}Po ratio of about one. Persons whose diet consists primarily of fish or meat ingest higher than average concentrations of ^{210}Po. The largest ingestions found occur in the Lapps and Eskimos because of the lichen - reindeer (caribou) - Lapp (Eskimo) food chain. The average intake reported for the Laplander is an order of magnitude higher than the northern middle latitudes due to the diet of reindeer.

The radiation dose to the body's tissues caused by the long-lived daughters is primarily due to the energetic alpha particles of ^{210}Po. At equilibrium, the beta contribution from ^{210}Pb and ^{210}Bi is 7.5 percent that of the ^{210}Po alpha energy, thus, it is generally neglected.

The whole body exposure attributed to all of the internal emitters is 18-25 mrem/y; the difference between the literature values appears to be the use of an average of male and female ^{40}K exposures *(2.1)* or the male exposure only *(2.2)*. In "normal" areas (designation used by UNSCEAR), the other internal emitters (not including ^{40}K) provide about 2 mrem/y. However, exposures from individual emitters such as ^{226}Ra and ^{210}Po as discussed can vary by an order of magnitude. The gonadal exposure shown for ^{210}Po in table 2-9 is 0.6 mrad/y which is for normal areas in the northern temperate latitudes. The exposure given for the artic regions is 7.2 mrad/y *(2.2)*. The exposure (table 2-9) for ^{226}Ra is 0.02 mrad/y which is for normal areas; but for areas such as Kerala, India, the gonadal exposure stated is 0.2 mrad/y.

External radiation

The naturally radioactive nuclides contribute significantly to man's external exposure. The radiation that causes the largest increment of exposure is generally gamma-ray radiation, but alpha and beta particle radiations also occur. For example, at one meter above the ground, gamma and cosmic rays produce 7 ion pairs/cm^3/s (I) in air, and beta radiation produces 13 I *(2.1)*. Normally, the beta radiation would produce no rem dose to the bone marrow or the gonads; but it is felt that in special situations, such as houses with dirt floors, significant individual exposures could occur.

In the United States, 90 percent of the population receives an annual dose ranging from 30-95 mrem. The average was 55 mrem/y with ^{40}K, the ^{238}U series, and the ^{232}Th series contributing 17, 13, and 25 mrem, respectively *(2.20)*. The radon daughters in air generally do not contribute much to this dose, only 0.1-0.5 μrem/h *(2.1)*. Measurements for many locations have been collected and averages by state obtained to estimate the exposure to the population of the United States. This method produced an average exposure for the United States of 60 mrem/y/person and the various state averages are shown in table 2-13 *(2.10)*. Other measurements and methods have presented averages of 77 mrem/y *(2.21)* and 43.7 mrem/y *(2.1)*.

Summary

Terrestrial radiation comes from radioactive materials in the crust of the earth. These materials contribute to man's exposure by direct radiation and by indirect radiation through ingestion and inhalation. The estimated annual, average, individual, internal radiation dose from selected natural isotopes in the United States is given in table 2-9. These data show that the terrestrial radionuclides responsible for the most significant exposures are ^{40}K, ^{238}U chain products, ^{232}Th chain products, and ^{87}Rb. The whole body exposure attributed to all internal radioactive nuclides is estimated to be 18-25 mrem/y.

In the United States, most of the population receive annual external terrestrial radiation doses ranging from 30-95 mrem/y depending upon location with an average of 55 mrem/y. ^{40}K, ^{238}U chain products and ^{232}Th chain products contributed 17, 13 and 25 mrem/y, respectively, to the terrestrial dose.

Environmental Radiation Ambient Monitoring System (ERAMS)

The ERAMS is a surveillance program of EPA's Office of Radiation Programs for measuring levels of radioactivity in air, air particulates,

Table 2-13. Estimated annual external gamma whole-body doses from natural terrestrial radioactivity *(2.10)* (mrem/person)

Political Unit	Average Annual Dose
Alabama	70
Alaska	60*
Arizona	60*
Arkansas	75
California	50
Colorado	105
Connecticut	60
Delaware	60*
Florida	60*
Georgia	60*
Hawaii	60*
Idaho	60*
Illinois	65
Indiana	55
Iowa	60
Kansas	60*
Kentucky	60*
Louisiana	40
Maine	75
Maryland	55
Massachusetts	75
Michigan	60*
Minnesota	70
Mississippi	65
Missouri	60*
Montana	60*
Nebraska	55
Nevada	40
New Hampshire	65
New Jersey	60
New Mexico	70
New York	65
North Carolina	75
North Dakota	60*
Ohio	65
Oklahoma	60
Oregon	60*
Pennsylvania	55
Rhode Island	65
South Carolina	70
South Dakota	115
Tennessee	70
Texas	30
Utah	40
Vermont	45
Virginia	55
Washington	60*
West Virginia	60*
Wisconsin	55
Wyoming	90
Canal Zone	60*
Guam	60*
Puerto Rico	60*
Samoa	60*
Virgin Islands	60*
District of Columbia	55
Others	60*
Total United States	60

*Assumed to be equal to the United States average.

deposition, surface and drinking water, and milk in the United States and territories. The samples are collected by Federal, State, or local governments and analyzed at the Eastern Environmental Radiation Facility in Montgomery, Ala. Sources of radiation and population centers were considered in determining the locations of the sampling sites. The main emphasis for ERAMS is toward monitoring levels of radionuclides such as iodine-131 which deliver relatively high population dose commitments and identifying trends in the accumulation of long-lived radionuclides in the environment, such as plutonium-238, -239, uranium-234, -235, -238, krypton-85, hydrogen-3 (tritium), cesium-137, and strontium-90.

Trends

A tabulation of all raw data from each sampling network is reported quarterly in Environmental Radiation Data by the Eastern Environmental Radiation Facility. Figures 2-3 through 2-16 depict the trends of radioactivity concentration versus time for each network. An examination of the graphs reveals for most plots a yearly cycle of concentrations of radioactivity which are attributable to fallout. This is explained by the atmospheric mixing between the troposphere and stratosphere in the spring of each year. The submicron radioactive particles from the stratosphere are thus pulled down into the troposphere where settling and washout bring these particles to the earth's surface as fallout.

In the section below, a linear model has been used to determine the presence of significant trends over the time period in question, usually July 1973 through June 1976. Typically, the model is of the form $y = Bx + A$, where B is the least squares estimate of the slope, x is the time variable, and y is the radionuclide level in conventional concentration units.

Radioactivity in air

In the ERAMS Air Program, airborne particulates are collected continuously at 21 sampling stations. An additional 51 sampling stations have been placed on standby. The filters at the sampling stations are changed one or two times per week, and the gross beta radioactivity concentration is measured on each filter in the laboratory. The monthly averages for airborne particulates at all stations are shown in figure 2-3 from July 1973 when the laboratory analyses were initiated under the ERAMS program. The data show a yearly cycle with highest concentrations occurring in the spring and the lowest concentrations in the fall.

The airborne particulates from the 21 air sampling sites are analyzed for uranium-234, -235, and -238. The uranium-234, uranium-235, and -238 concentrations in figures 2-4, 2-5, and 2-6 show an increase from 1973 to a peak concentration in mid-1974, and fluctuations with an overall downward trend extending into 1976.

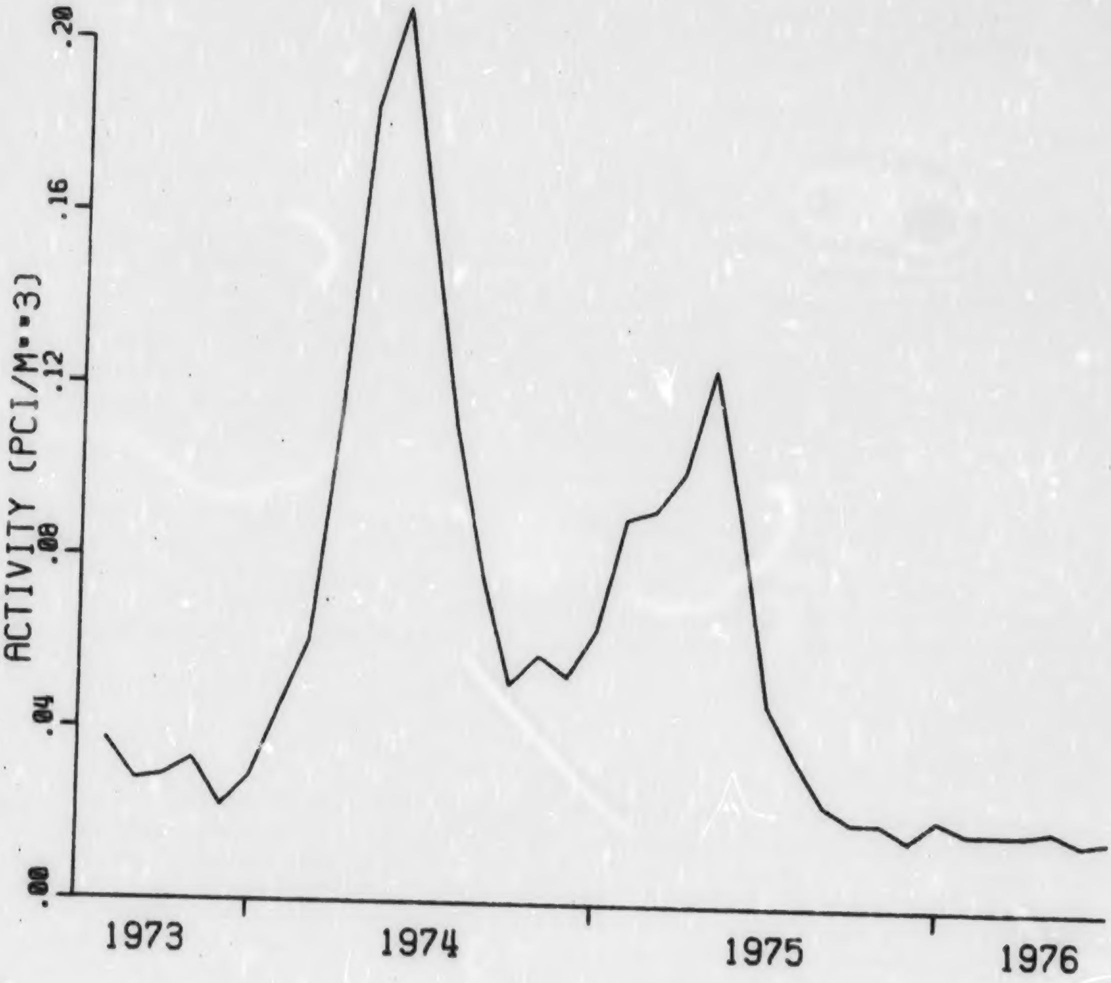

Figure 2-3. Gross beta in airborne particulates: network averages

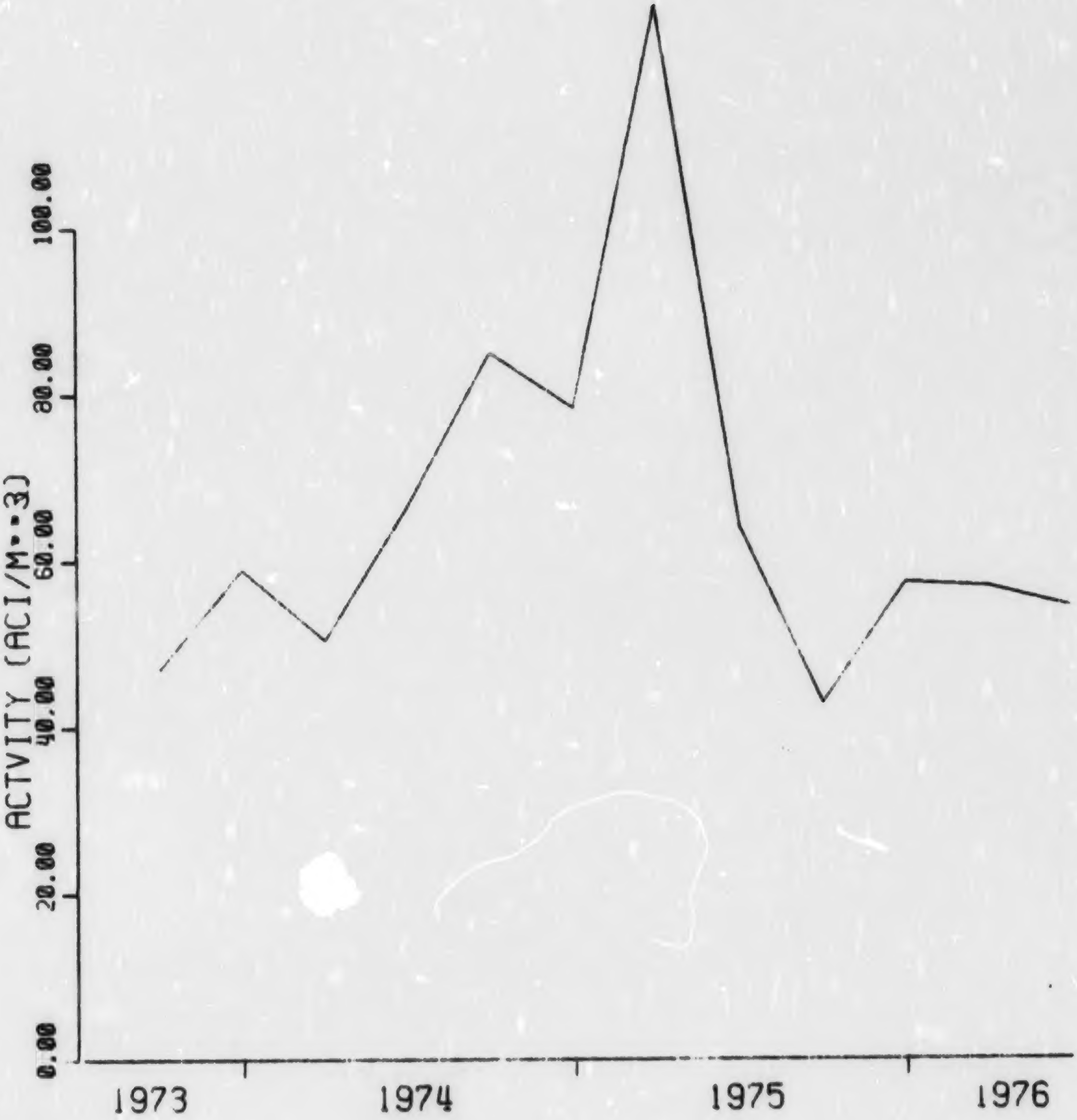

Figure 2-4. Uranium-234 in airborne particulates: network averages

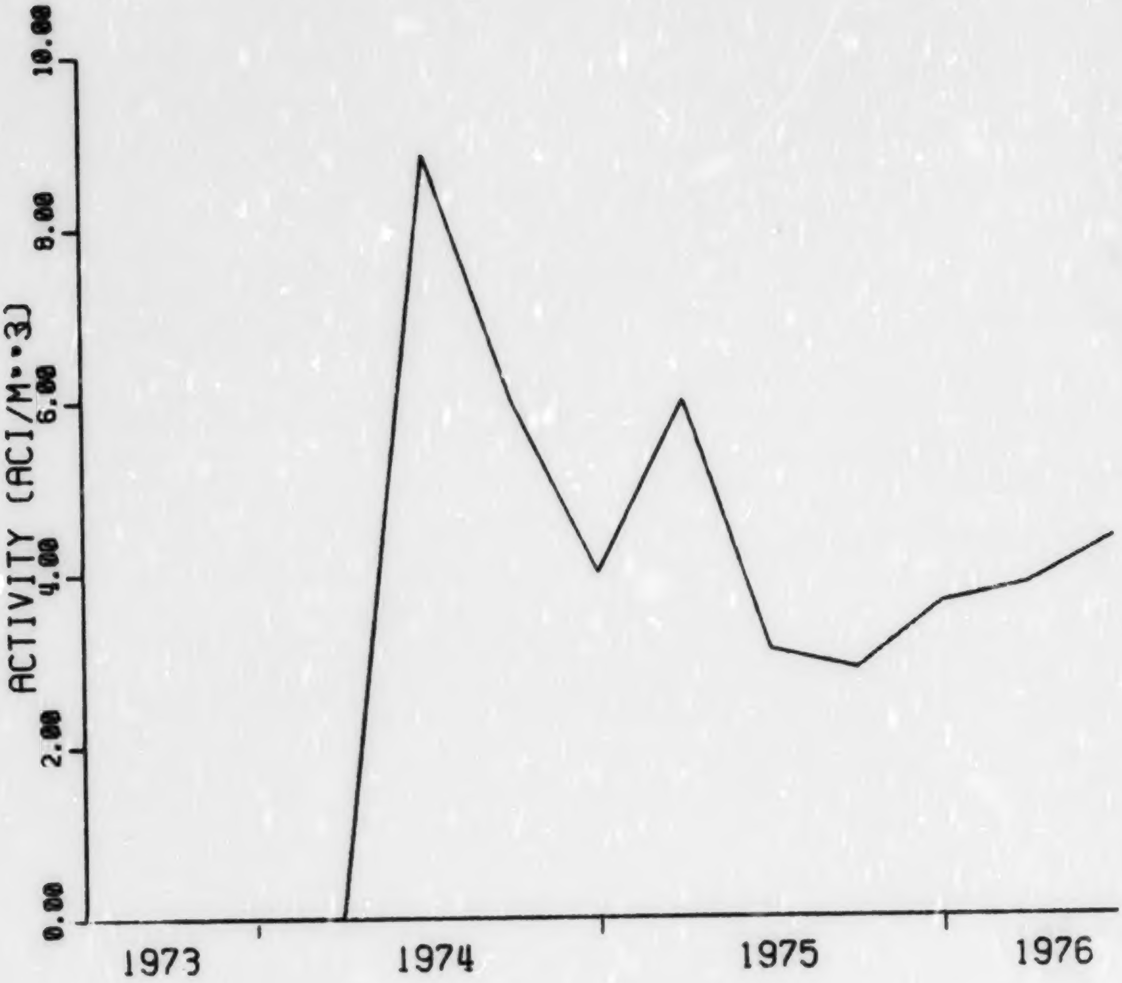

Figure 2-5. Uranium-235 in airborne particulates: network averages

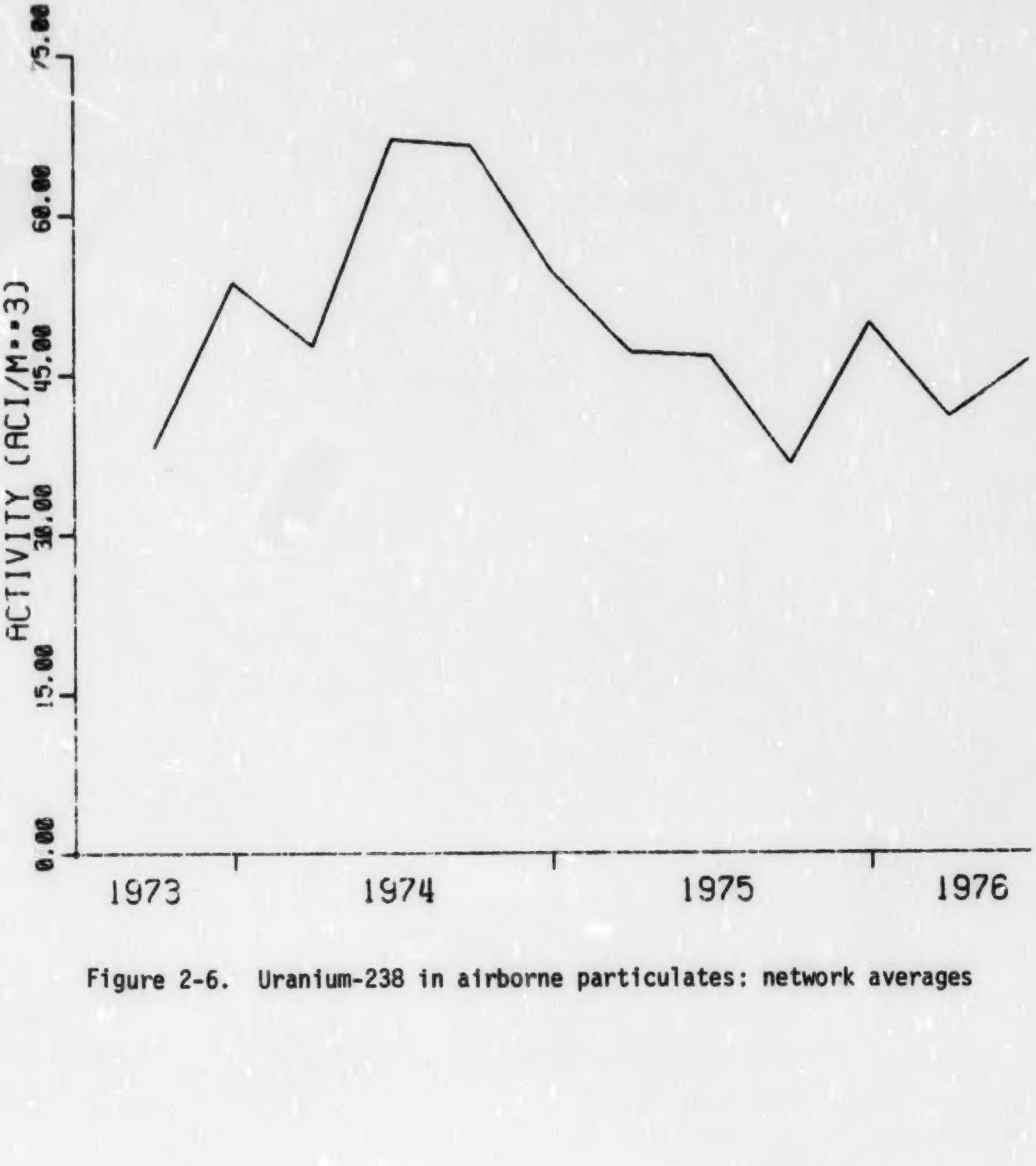

Figure 2-6. Uranium-238 in airborne particulates: network averages

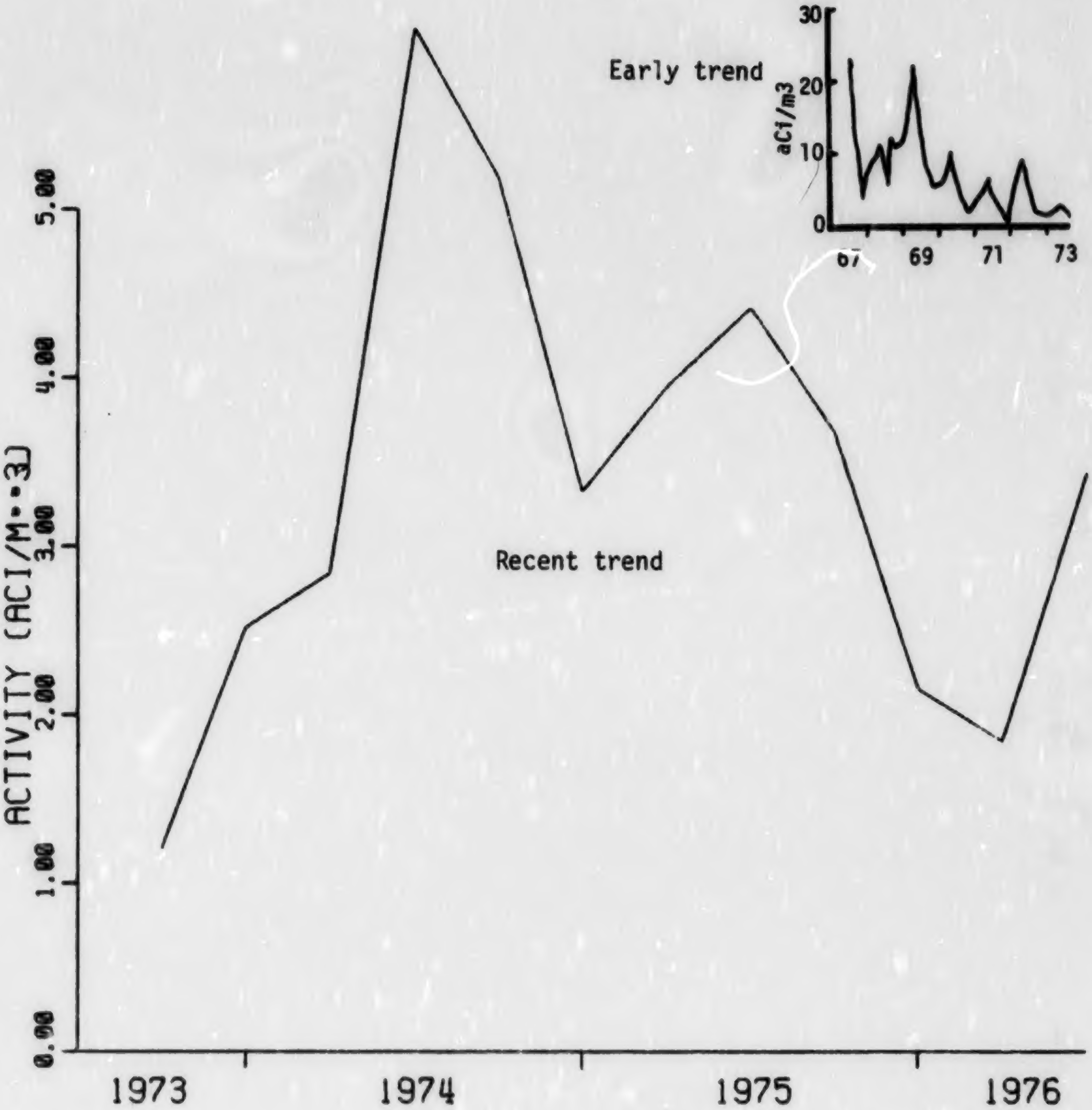

Figure 2-7. Plutonium-238 in airborne particulates: network averages

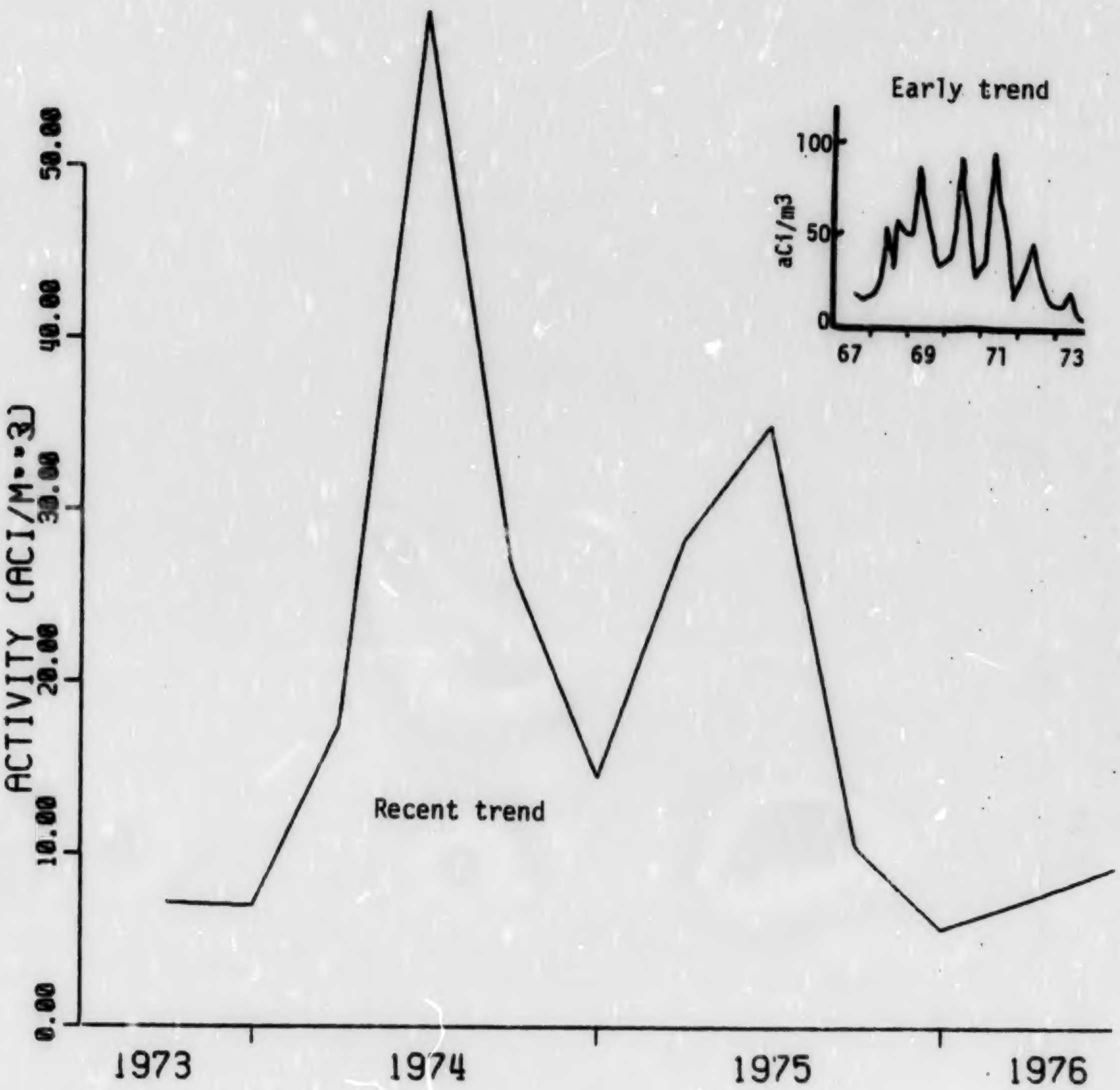

Figure 2-8. Plutonium-239 in airborne particulates: network averages

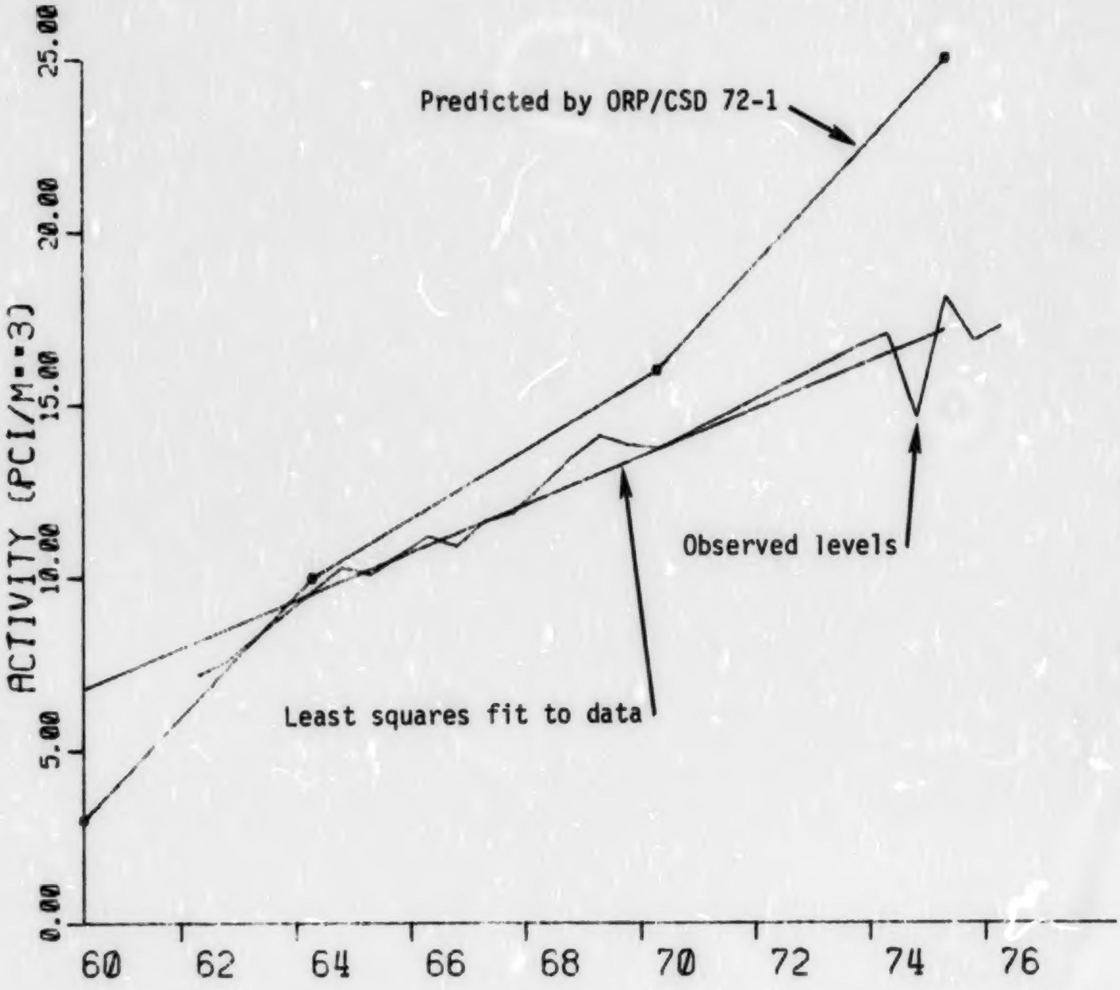

Figure 2-9. Krypton-85 in air (predicted and observed levels)

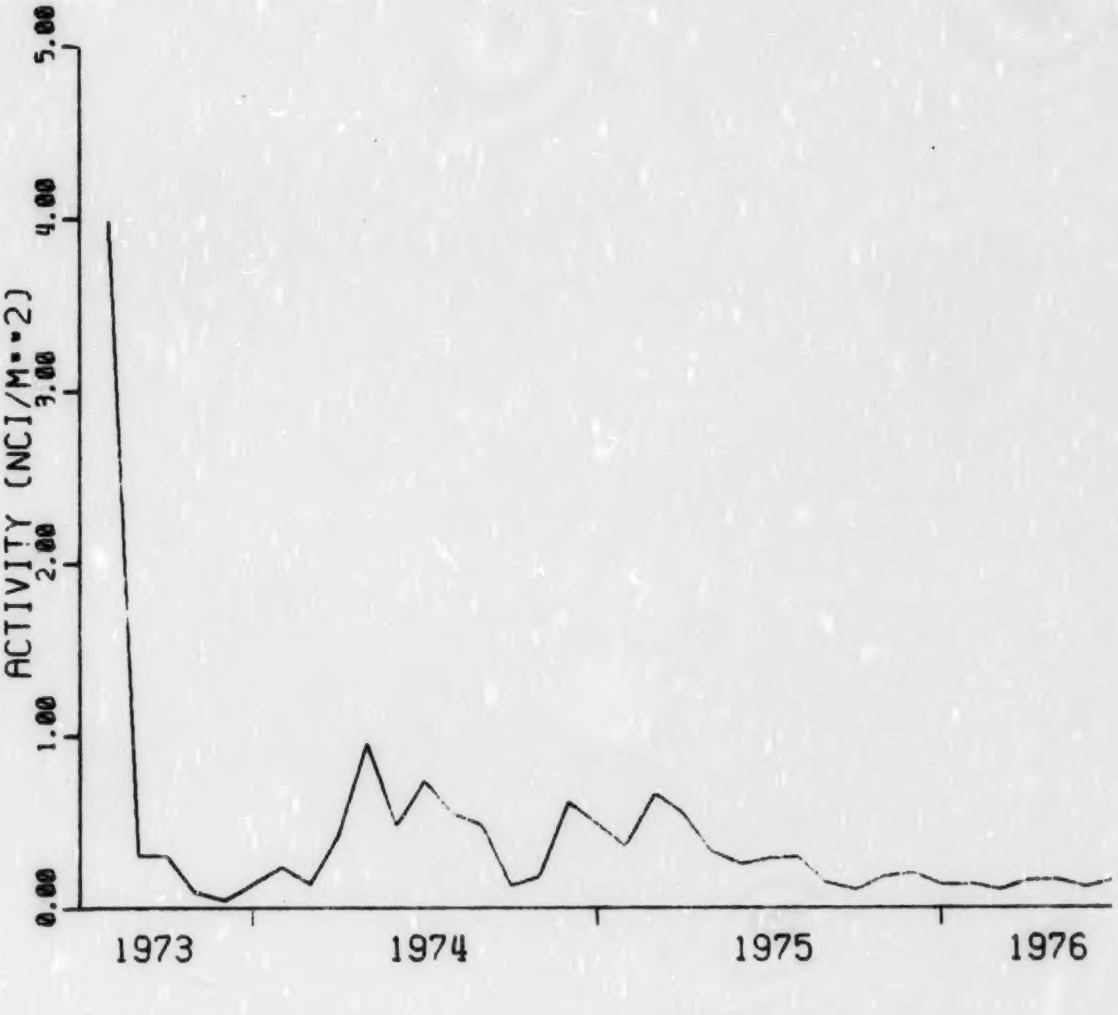

Figure 2-10. Gross beta in precipitation: network averages

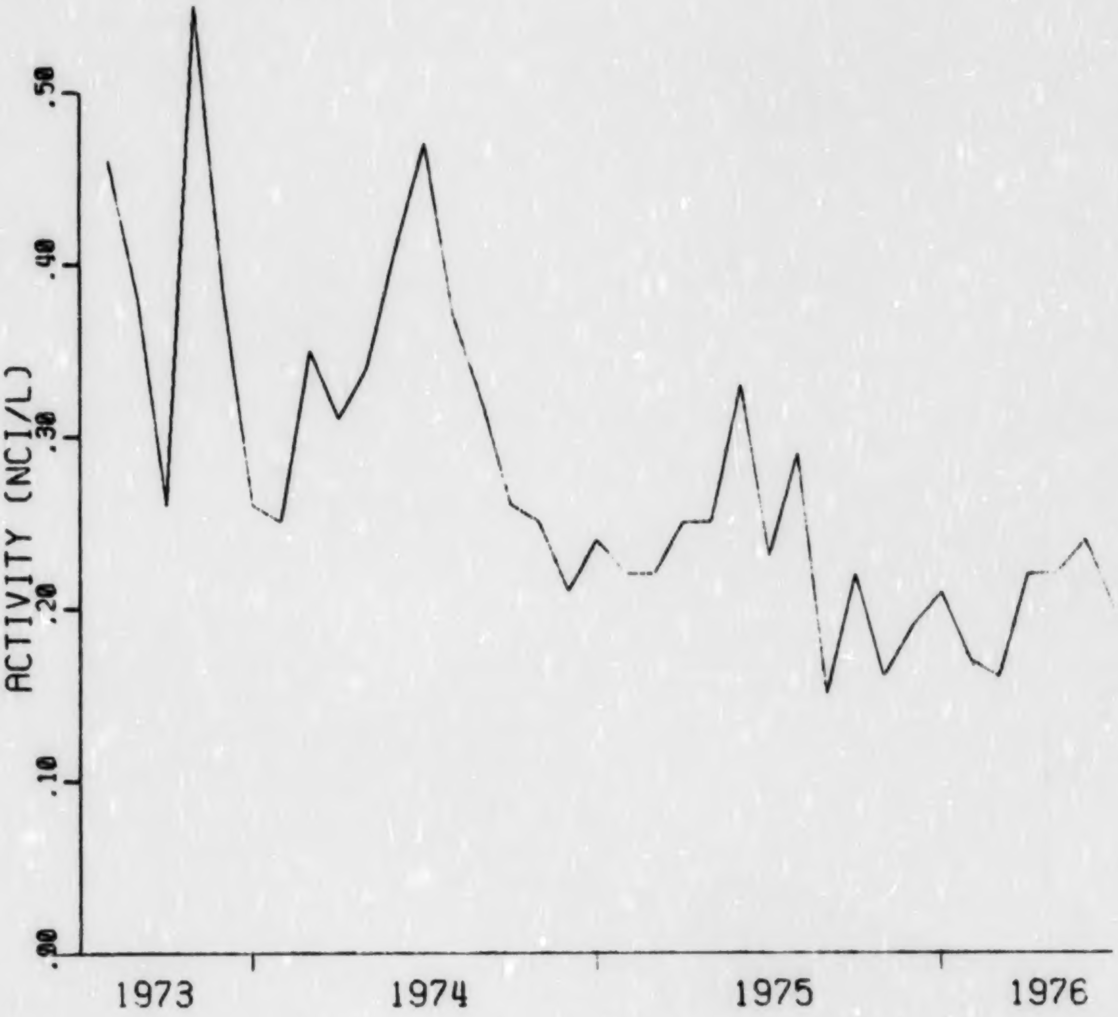

Figure 2-11. Tritium in precipitation

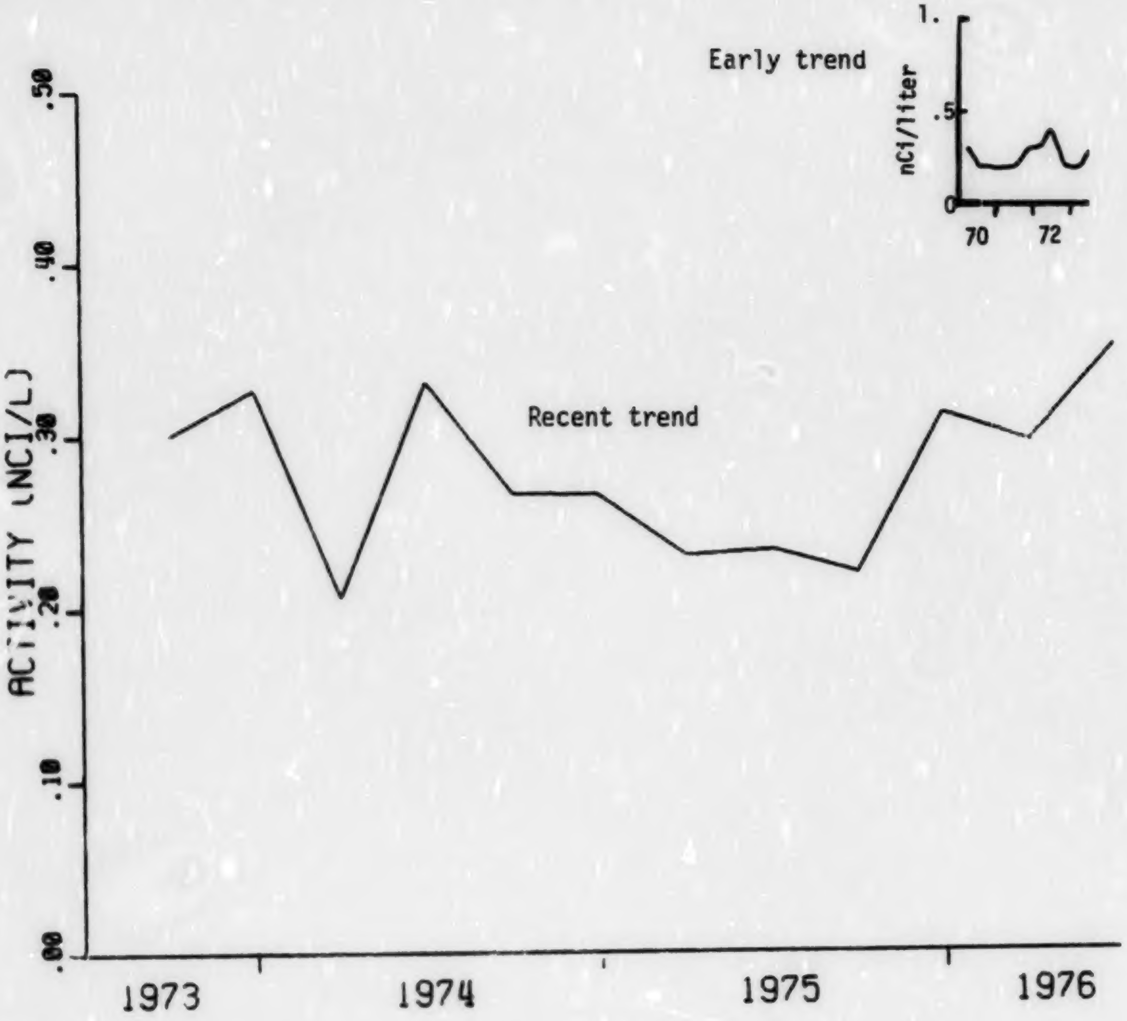

Figure 2-12. Tritium in drinking water: network averages

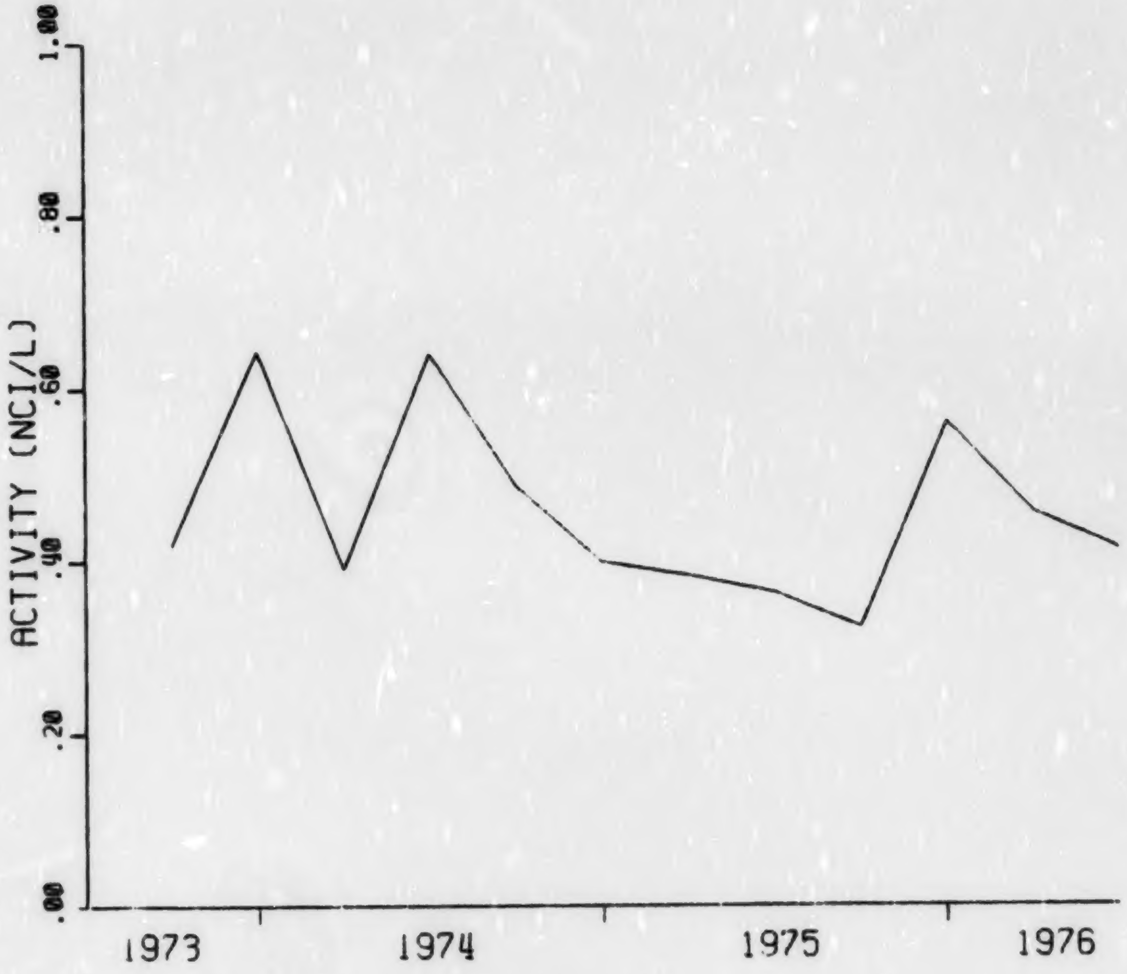

Figure 2-13. Tritium in surface water: network averages

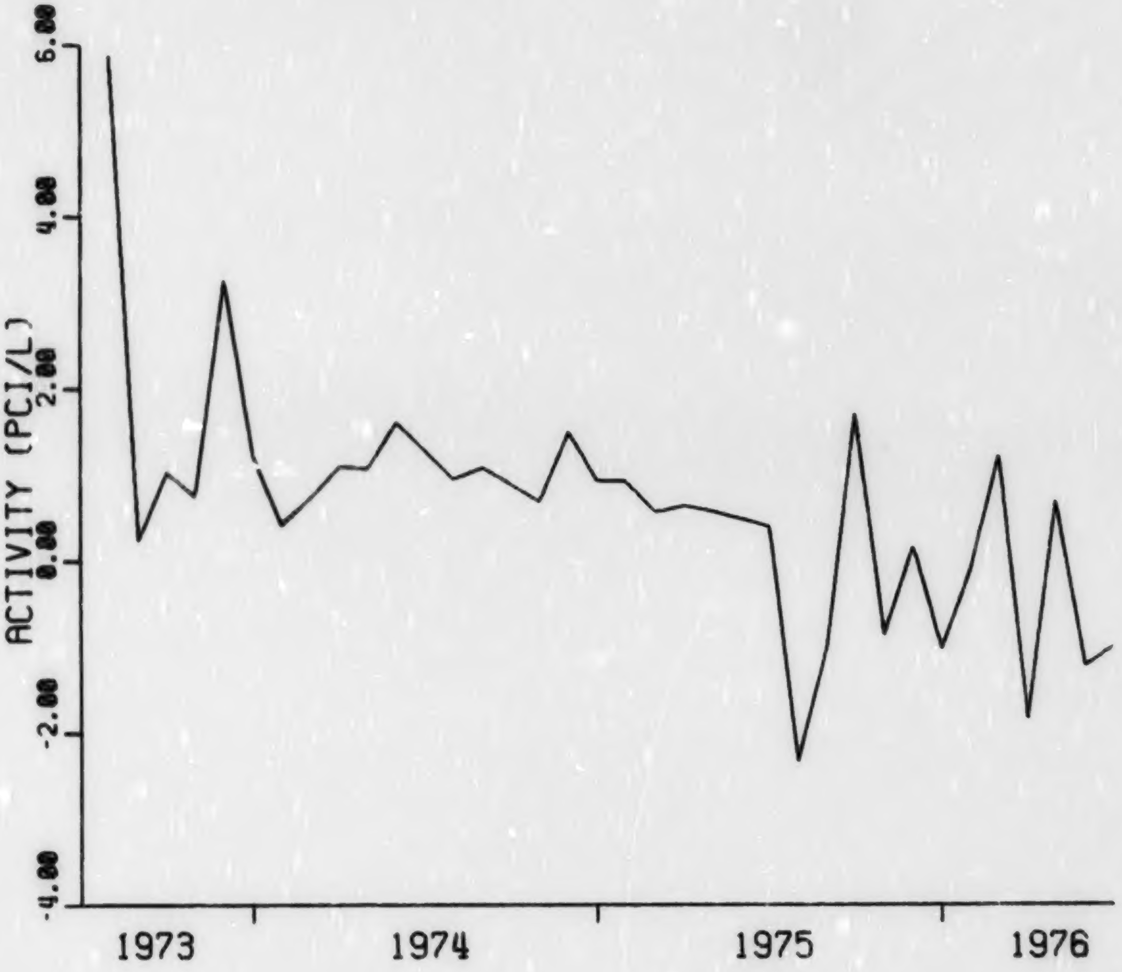

Figure 2-14. Iodine-131 in pasteurized milk: network averages

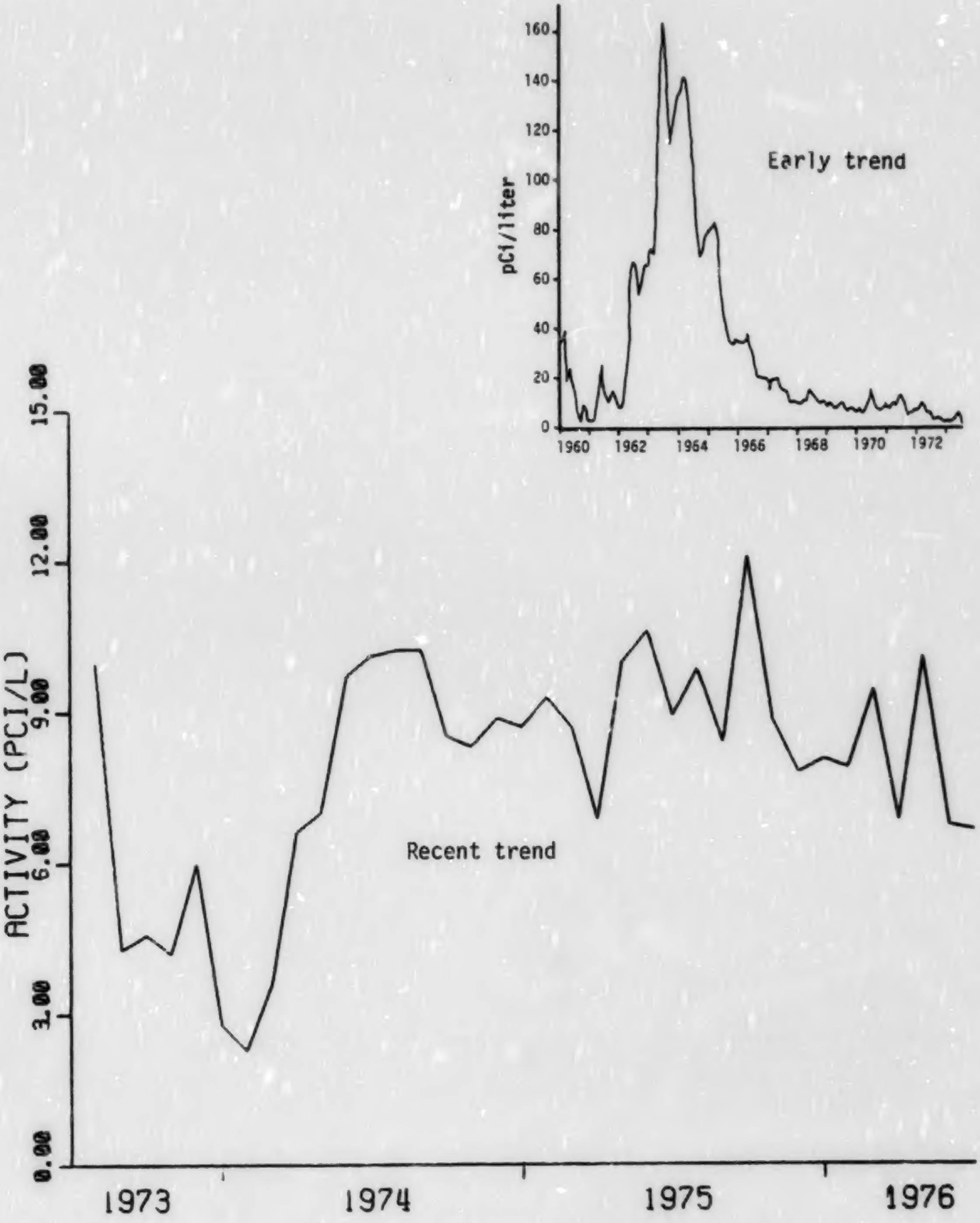

Figure 2-15. Cesium-137 in pasteurized milk: network averages

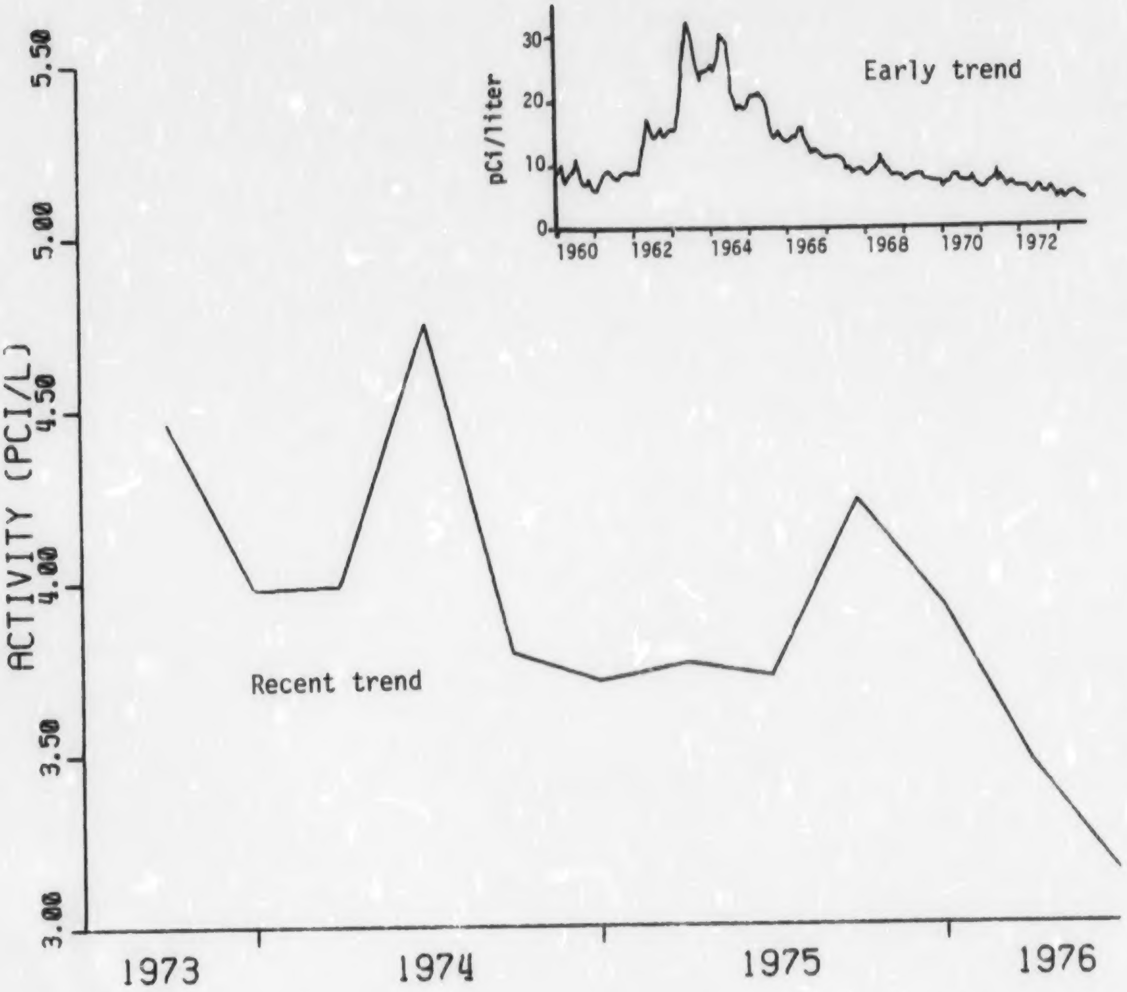

Figure 2-16. Strontium-90 in pasteurized milk: network averages

Air particulate data for uranium-234 and uranium-238 were tested according to the linear model described above and for each the slope for estimating a long-term trend was not statistically significant.

Plutonium-238 and -239 analyses are currently performed on the air particulates from the 21 air sampling sites. However, plutonium-238 and -239 measurements have been conducted since 1967 on samples from selected air particulate sampling stations. The results since 1967 are plotted for both radionuclides in figures 2-7 and 2-8 and show a yearly cycle with the peak concentrations in the spring and the minimum concentrations in the fall.

The linear model was again employed for plutonium-238 and plutonium-239 in air filters over the period, July 1973-June 1976 and each slope for estimating trends was not significant.

Krypton-85 concentrations have been measured in air samples taken from stations in the United States and abroad from April 1962 to June 1976. The data are shown in figure 2-9 together with predictions of krypton-85 levels by the EPA (Klement, et al.) and the linear model using atmospheric concentration as the variable y and time as variable x, the linear trend was studied using the model described above.

The correlation coefficient for the model was 0.92 and the 95 percent confidence level on the slope was 0.0579 ± 0.0054, indicating a significantly positive slope with units of pCi/m^3-month. Behavior of this trend will be hereafter continuously monitored with regard to future nuclear power production and reprocessing.

Radioactivity in precipitation

Gross beta radioactivity measurements are also performed on precipitation samples collected at the 21 air sampling sites. Figure 2-10 shows the fallout in mid-1973 from a nuclear detonation by the Peoples Republic of China and a spring rise in 1974. Using the linear model as described above, an F ratio of F(1,34) = 5.12 was obtained which is significant at the 95 percent level. The 95 percent confidence interval on the slope was [-0.0223 ± 0.0197] pCi/m^2-month which is significantly negative, i.e., a downward trend.

One may notice that the high level of gross beta in precipitation is well correlated with the pasteurized milk levels of iodine-131, cesium-137, and strontium-90, but not well-correlated with gross beta levels in airborne particulates (see figure 2-3).

Tritium concentration is measured on a monthly precipitation composite at the same locations as the 21 air sampling sites. The data since 1967 shown in figure 2-11 indicate the yearly cycle of higher concentrations in the summer and lower concentrations in the winter.

Using the linear model over the July 1973-June 1976 period, a significant downward trend was found for tritium in precipitation. The observed F ratio is F (1,34) = 35.5, and the 95 percent confidence interval on the slope is [-0.00639 ± 0.00214].

Radioactivity in water

Tritium is measured in drinking water at 77 sampling sites which are at either major population centers or selected nuclear facility environs. The data since 1970 shown in figure 2-12 indicate about the same average concentration overall with no trend.

Tritium is also monitored in surface waters which are downstream from nuclear facilities. The data during the July 1973-June 1976 period is shown in figure 2-13.

A linear model as described above was used to test for a significant slope in the data. The observed F ratio was F(1,10) = 1.007 which is not significant at the 95 percent level. The observed 95 percent confidence interval on the slope is [-0.0089 ± 0.0177] having the physical units of pCi/liter-calendar quarter.

Radioactivity in milk

The ERAMS milk program consists of 65 sampling stations. Figure 2-14 shows the iodine-131 concentration trend. Moderate fluctuations are observed over the time period, July 1973-June 1976, and a slight downward trend may be seen.

A linear model yielded a F ratio of F (1,34) = 20.8 for the 36-month period which is significant at the 95 percent level. The significant decrease in iodine-131 levels are further indicated by the 95 percent confidence interval of [-0.082 ± 0.036] pCi/liter-month.

Figure 2-15 and 2-16 depict the cesium-137 and strontium-90 concentrations in milk from 1960. Both graphs reflect the fallout from atmospheric detonations in the early 1960's and a decline to present levels. The linear model was used for the ^{90}Sr data over the July 1973-June 1976 period. The observed F ratio was F(1,10) = 7.58 which is significant at the 95 percent level. The observed 95 percent confidence interval on the slope is [-0.0778 ± 0.05648] pCi/liter-calendar quarter which indicates a significant downward trend in strontium-90 levels in milk over this period.

Cesium-137 data for the period fiscal year 1974-fiscal year 1976 was available in machine readable form for the regression analysis. The observed F ratio for this period was found to be F(1,34) = 7.72 which is significant at the 95 percent level. The confidence 95 percent interval on the slope is [0.0966 ± 0.0695] pCi/liter-month. Although this slope is slightly positive, the magnitude of cesium-137 levels in milk are far below those observed in the past two decades.

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Chapter 3 - Technologically Enhanced Natural Radiation

This section deals with exposures received in the ambient environment from materials containing naturally radioactive nuclides. To distinguish the exposure from these materials (which can be controlled) from the exposure received from the natural terrestrial and cosmic radiation sources (generally uncontrollable exposure), the term technologically enhanced natural radioactivity or TENR has been suggested by Gesell and Prichard *(3.1)*.

The TENR exposure comes from the natural radionuclides that have been redistributed by some activity or technology undertaken by people, such as mining or development of wells. Thus, the nuclide is either brought to the surface of the earth where exposures can occur, the surface of the earth which previously provided attenuation or acted as a diffusion barrier is removed, or persons go into the earth in natural caves and manmade excavations where they are exposed. Since some form of technology is involved, the resulting exposure can be controlled, and if the envisioned control measures are cost effective, then it would follow that the exposures should be controlled.

The creation of the TENR classification has been suggested so that agencies with responsibility for issuing guidance for radiation exposures and setting exposure standards can differentiate between natural (background) exposure and the occurrences which were previously referred to as natural radiation anomalies. For instance, if one obtains a gamma radiation measurement of 100 μR/h in Grand Junction, Colo., the extrapolated yearly exposure of 876 mrem/y is not due to background exposure, as it might be in parts of India or Brazil; rather, the excess gamma (788 mrem/y, assuming 10 μR/h background) is due to TENR (in all likelihood, uranium mill tailings). It is suggested that the development of a TENR category would do away with the present inconsistent attitude that allows concern for exposure to manmade sources of radiation (radioisotopes and nuclear reactors) and ignores the equivalent levels of exposure if they are from a material that was not designed to produce radiation, such as fertilizer. TENR would not be limited to the surface of the earth. Such exposures as that received from cosmic radiation during supersonic air travel would also be technologically enhanced natural radiation. The sources of TENR which are presently being considered are discussed below, and it is estimated that many other technologies may be causing unknown significant exposures.

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Ore Mining and Milling

Naturally radioactive nuclides are present in various ores that are not mined for a naturally radioactive element such as uranium. The concentration of the natural radioactive elements will vary even in the same type of ore in different geographic areas. Thus, finding certain concentrations of radium in association with an ore in one location does not necessarily mean that the same type of ore may present a possible health hazard in another geographic location. For instance, the wastes from a fluorspar operation near Golden, Colo., produce gamma radiation levels of about 1 mR/h, and the waste pile is controlled by the State's Division of Occupational and Radiological Health; however, fluorspar ore near Beatty, Nev., produces radiation typical of background levels.

The evaluation of possible radiological health hazards associated with ore and waste products is really just beginning. The fact that the radiation was present in various ores has been known; but by law, unless the ore contained uranium or thorium in concentrations that equal or exceed 0.05 percent (separately or combined), the possession, processing, and disposal of the ore is not licensed or controlled. However, this does not mean that nonlicensed material is safe. Proof that the removal of uranium from uranium ore with less than 0.05 percent remaining in the waste tailings did not render the tailings harmless so that they could be used for construction material, was finally accepted in about 1970. Thus, wastes from all mining and milling activities should be evaluated before disposal or reuse.

The Environmental Protection Agency (EPA) and its predecessor programs in the U.S. Public Health Service (PHS) have been involved with the Atomic Energy Commission (AEC), Energy Research and Development Administration (ERDA), and the States in evaluating the possible health effects from uranium mill tailings. The EPA, in cooperation with State Health Departments, is now in the process of evaluating the products, byproducts, and use of waste associated with the phosphate industry *(3.2,3.3)*.

Uranium Mill Tailings

The wastes from uranium mills will be discussed in this section and uranium mining and milling will be discussed in a later section dealing with the uranium fuel cycle. These wastes, uranium mill tailings, have been the subject of various investigative research projects since the 1950's, when potable and agricultural water supplies in Farmington, N.M., were determined to have high radium concentrations. The source of this radium was eventually traced to the uranium mill at Durango, Colo., which was located on the Animas River, a tributary of the San Juan River. The wastes from uranium mills, at that time, were usually discharged directly to the environment, and the material could enter directly or seep into any nearby rivers. This practice was ended, and storage lagoons or tailings ponds came into use. These ponds did not require a new technology since raffinate and pregnant liquor ponds (for mills with dual uranium/vanadium circuits) were already in use.

Little or no sealing or bottom-of-pond preparation was done, since in theory, the fines contained in the tailings slurry were expected to fill in the pores or void spaces in the soil and prevent seepage. In addition, most of the tailings ponds are designed with catchment basins downgradient from the dike or dam where the seepage (that comes to the surface) is collected and pumped back to the pond system. However, present reports indicate that seepage is not prevented by "fines-sealing," and in some of the largest mill waste retention systems, about 30 percent of the ponded liquids seep out of the pond and into the surface or ground water *(3.4-3.6)*. At the large mills, 30 percent of the mill effluent can be significant, on the order of 674 million liters per year. It is estimated that this has contributed 1.1 curies of radium to the ground water in the vicinity of the mill *(3.7)*.

The ore feed to the mills has been estimated to average 0.25 percent U_3O_8. Usually, the radioactive nuclides of the ^{238}U decay chain are in equilibrium. Thus, the uranium daughters will all have the same activity. This activity may be calculated by multiplying 290 times each 0.1 percent U_3O_8. Thus, 290 x 2.5 = 725 picocuries per gram (pCi/g) of tailings. Almost all of the radium and thorium daughters contained in the ore feed eventually are discharged to the waste system. Thus, the uranium mill tailings will contain about 725 pCi/g of radium-226 and thorium-230, based on the average 0.25 percent U_3O_8.

Uranium mill tailings piles are currently categorized as active or inactive depending on the site activity, and the following subclassifications can be used:

1. Active (in use). These piles are located at an active uranium mill site and are receiving wastes.

2. Active (not in use). These piles are located at an active site; but they have been filled and are no longer receiving wastes, or the mill has been temporarily closed for modification.

3. Active (standby). The mill has been closed temporarily to upgrade and repair the facility but will be reopened.

4. Inactive (standby). These sites exist at mills that are not processing ore. The owner has put the mill in "moth-balls" but might reopen if economically beneficial.

5. Inactive (controlled). Mill buildings may have been dismantled, but the owner is still responsible for the tailings piles under authorities held by a State or Federal agency.

6. Inactive (abandoned). No mill owner responsibility (either the land has been sold or returned to the original land owner).

The radioactivity contained in these piles will, if not controlled, migrate to and contaminate the environment through air and water pathways. The magnitude of the possible population exposures, in general, can be estimated for the various classifications depending on the presence or absence of ponded liquid on the surface of the particular tailings pile. As viewed at present, the pathways involved that can result in radiation exposure to the general public from uranium mill tailings are:

1. Whole body gamma irradiation directly from the pile itself or from the deposition of windborne material.

2. Deposition of radionuclides in the body or in an organ of the body because of the ingestion of water or food that has been contaminated by material from the milling operation.

3. Deposition of radionuclides in the body or in an organ of the body because of inhalation, primarily alpha irradiation of the pulmonary region. Deposition in other areas of the body can also occur after inhalation if the material is cleared from the pulmonary region.

If the surface of a tailings pile is covered with liquid, the tailings material cannot be removed by the wind, and the water will slow up the radon being exhaled from the solids below. The water, however, may seep out the bottom or the sides of the tailings pond and the radium can enter the environment, or as the water seeps through the underlying tailings solids, additional radium can be dissolved by leaching.

EPA believes that the radiation dose to the pulmonary region of the lung is the critical pathway, but population exposure by the three modes previously mentioned may be prevented by either one or a combination of two different control actions: one, controlling and stabilizing the tailings pile which will also protect the surrounding environment; and two, providing land exclusion areas between the tailings piles and the general population. The second method, although preventing exposure to people, does not protect the immediate environment.

As soon as a tailings pond no longer has liquid added to it, the tailings begin to dry due to evaporation and seepage. Eventually, the surface will dry, allowing the wind to pick up the particulate material. For this mode, thorium-230 is believed to be the critical nuclide, exceeding the radiation concentration guide in some cases; however, radium-226, polonium-210, and lead-210 are also usually present.

During the constant radioactive decay occurring in all of the three natural chains discussed in terrestrial radiation, an element, which is an inert or noble gas, named radon is formed. The isotopes are ^{219}Rn called, historically, actinon from the uranium-235 chain; ^{220}Rn called thoron from the thorium-232 chain, and ^{222}Rn called radon from the uranium-238 chain.

Uranium-235 is normally present in very small quantities and the half-life of actinon (^{219}Rn) is 4.0 seconds; thus, there will never be much ^{219}Rn exhaled from tailings material. Similarly, thoron (^{220}Rn) also has a short half-life (55 seconds), and thoron would not diffuse very far in tailings material. The subsequent daughters after radon are metals which form particulates, thus; they will be trapped in the tailings matrix. Because of the low abundance and very short half-lives, these two radon isotopes are not usually considered to contribute to the health effects calculated for uranium mining and uranium mill tailings. However, if one was associated with a material that contained larger concentrations of thorium-232, such as thorium mining or a manufacturing process that utilized thorium, then there might be a hazard created by the thoron daughters.

Radon-222, the radioactive radon isotope from the uranium-238 decay chain, has a relatively long half-life (3.8 days). The elasticity or relaxation length in the tailings material will be about 1.5 meters, or 1.5 meters of soil will reduce the radon exhalation by about two-thirds (1/e). This is about 10 times greater than the thickness required to reduce the gamma ray exposure rate by the same factor *(3.8)*.

Originally, the concern regarding radon was exposure to uranium miners. The radon-222 itself produces only about 5 percent of the radiation dose (alpha energy) that contributes to the biological hazard. The main hazard comes from the radon daughters, specifically, the short half-life radon daughters. These daughters are ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po, also referred to as RaA, RaB, RaC and RaC', respectively. Since more than one nuclide is involved, a total energy unit was developed which precluded having to determine the concentration of each nuclide. This unit, the working level (WL), was also designed to be a safe occupational level of exposure. Thus, at the time of development, a uranium miner could work in an atmosphere containing one WL and the exposure received would be acceptable. (This "safe" level has now been reduced by a factor of 3).

One WL is defined as any mixture of short half-life radon daughters in a liter of air which will ultimately produce 1.3×10^5 MeV of alpha energy. Also, 100 pCi of ^{222}Rn per liter of air in equilibrium with its short half-life daughters will produce 1.3×10^5 MeV of alpha energy or 1 WL of exposure. Further, if a miner worked 8 hours per day, 5 days per week for a month (actually based on 170 hours of exposure) in a 1 WL atmosphere, then he would receive a one working level-month exposure (WLM). This same exposure for one year would be 12 WLM which was originally a "safe" yearly occupational exposure.

The studies or risk associated with the inhalation of radon, specifically, the short half-life radon daughters, were originally limited to miners and the mining industry. Most dealt with the uranium industry. With the discovery that uranium mill tailings with substantial radium concentrations were being used for construction material, health officials suspected that elevated WL exposures would be present in the homes built with or over tailings because the radon could diffuse through the material used in the structure. Once radon reaches the inside of a habitable structure, the radon daughters that are formed can lead to elevated exposures of the occupants.

Elevated radon daughter exposures in the "new" environment, the home, were first observed in Grand Junction, Colorado, in 1966; and it was subsequently determined that tailings had been supplied for construction purposes since about 1953. In August 1970, the Public Health Service provided guidance to the State of Colorado concerning gamma radiation and radon daughter exposures. Referred to as the Surgeon General's Guidance, the document provided for an upper level, above which remedial or corrective action was suggested; a lower level, below which no action was believed necessary; and an intermediate region where the decision for action was based on further evaluation of the specific location. The working level guidance values were 0.05 WL and 0.01 WL, and the gamma radiation values were 0.1 mR/h and 0.05 mR/h above background, upper and lower guides, respectively. As a result of the Grand Junction studies, two computer data bases were developed. Both of these systems are still in use, and printouts are furnished to the users by the EPA routinely and upon request. The active gamma data base is now operated for the State of Colorado by a Grand Junction ERDA contractor.

Gamma surveys of Mesa County, Colorado, structures, with the owners approval, were made by radiation monitors using portable radiation detection instruments (NaI scintillometers). Initial surveys in other communities were performed with a mobile gamma scanning unit developed by the PHS facility in Las Vegas, Nevada. The discovery of radiation anomalies in other communities led to the development of a more sensitive mobile gamma scanning unit.

The initial surveys with the new unit, which belonged to the AEC, were performed in Grand Junction and the necessary adaptations for its use were developed by Lucius Pitkin, Inc. (LPI), the prime contractor for the AEC at the Grand Junction Operations Office. By August 1972, surveys of about 90 communities in 10 Western States (Arizona, Colorado, Idaho, New Mexico, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming) were completed by LPI for the EPA. Any anomalies in the natural gamma radiation levels discovered by the contractor were provided to the EPA and investigated by an EPA field survey team. Reports for each community and a State summary of the community surveys were then furnished to the appropriate State agencies.

Studies of the radon exhaled from uranium mill tailings sites were initiated in 1967. The PHS, AEC, and the Colorado and Utah State Health Departments cooperated in the joint project. The results of this study indicated that, beyond the distance of 0.5 mile from the tailings pile, the ambient radon level could not be statistically distinguished from the community's background ^{222}Rn level *(3.9, 3.10)*.

The background concentrations of radon-222 (pCi/ℓ) in the four community studies for the period 1967-1968 were: 0.5 pCi/ℓ, Durango, Colo.; 0.3 pCi/ℓ, Monticello, Utah; 0.4 pCi/ℓ, Salt Lake City, Utah; and 0.8 pCi/ℓ, Grand Junction, Colo. *(3.9)*.

A second year study was performed at Grand Junction, Colorado, during 1974 and 1975. This study confirmed the original background concentration (0.8 pCi/ℓ); however, the average radon concentration over the surface of the uranium mill tailings pile was three times higher after stabilization (1975) then before the pile was stabilized (1968). Statistical studies performed also indicated that in the downwind direction the elevated radon concentration was significant. Although the concentration did not exceed 1.0 pCi/ℓ beyond about 5/8 of a mile, the increase in the downwind direction was significant; it was different than the upwind stations *(3.11)*.

Environmental surveys have also been performed for tailings piles at Tuba City, Ariz.; Mexican Hat, Utah; Monument Valley, Ariz.; and Salt Lake City, Utah *(3.12-3.16)*. All of these surveys indicated that the sites should not be used without stabilization of the tailings piles, and that the surface of the pile should not be used or developed.

These above studies, although performed at different communities and utilizing data collected at multiple locations within the community, have all been concerned with only one major source of radon, the uranium mill tailings pile. The EPA has now also completed a study concerned with multiple radon sources in an area. This study was performed in the Ambrosia Lake area of New Mexico *(3.17)*. The radon sources in this area include inactive uranium mill tailings piles, active uranium mill tailings piles, uranium mills, ore storage piles at mines and mills, windblown tailings and/or ore dust, natural uranium-bearing formations, mine ventilation exhaust, and ion exchange plants. This study indicates that ambient outdoor radon concentrations and the indoor radon daughter levels (WL) exceed the typical background level in the vicinity of the uranium mines and mills *(3.17)*.

The concentrations detected at Ambrosia Lake appear similar to levels detected in other studies, i.e. elevated radon and WL measurements are found in close proximity to radon sources; but beyond some distance, such as a half mile, concentrations do not exceed 1 pCi/ℓ ^{222}Rn. However, since differences in the downwind direction are measurable, efforts to evaluate the radiation exposures to the general population occupying the immediate vicinity at all of the uranium mining and milling operations should be undertaken.

In 1973, the AEC and EPA indicated to Congress that comprehensive studies should be made of all of the uranium mill tailings piles under an overall plan rather than surveying each pile separately. The above recommendation was accepted, and a joint AEC/EPA project was started.

During April 1974, a report was prepared for the Climax Site in Grand Junction, Colo. This report was used as the format for the other Phase I site reports. The Grand Junction work was followed by visits to each of the other sites by a team consisting of an AEC representative, EPA representatives from the Office of Radiation Programs in Las Vegas and the EPA region concerned, a representative of the concerned State's radiological health program, and, when possible, a representative of the milling company. Surveys at all of the sites were completed in May, and the Phase I reports were submitted to Congress in October 1974 *(3.18)*. The sites included in these reports are shown in table 3-1.

After submission of the Phase I reports, the second phase was started. The purpose of the planned Phase II work at the inactive tailings pile sites was to determine the costs of various types of remedial action for a particular site. This work will be accomplished by an architect-engineering firm under contract to ERDA. The first Phase II study was started in mid-1975 at the Vitro site in Salt Lake City, Utah. The selected architect-engineering firm (Ford, Bacon and Davis, Utah, Inc.) issued the report on this site in April 1976 *(3.19)*. The document contains considerations of the following topics:

1. Vitro Mill Site Description
2. Radioactivity and Pollutant Impact on the Environment
3. Impact of the Vitro Site on Land Use and Social Values
4. Recovery of Residual Uranium Values
5. Mill Tailings Stabilization
6. Offsite Remedial Action
7. Long-Term Storage Site Selection
8. Vitro Site Remedial Action
9. Remedial Action Criteria

The remedial actions considered in the Phase II report include controlling only the access to the site, stabilizing the pile in place, and removing the tailings from the site. The removal option includes relocation at eight different sites; four sites in the Salt Lake Valley and four outside of the valley. The total estimated costs for each of the 10 remedial action options considered varied from $550,000 to over $30 million *(3.19)*. Phase II data are expected to be collected from all of the inactive uranium mill sites (table 3-1) by the end of the 1976 calendar year. At present, draft Phase II reports have been issued for the four Navajo Nation sites: Mexican Hat, Utah; Shiprock, N.Mex.; and Monument Valley and Tuba City, Ariz.

The EPA has also been directly concerned with remedial action at the inactive uranium mill site near Shiprock, N.Mex. This site was operated from 1954 to 1968. The operating companies during this period

Table 3-1. Phase I inactive uranium mill site reports *(3.18)*

State	Location	Present owner* or former mill owner**	Size of tailings pile (tons)
Arizona	Monument Valley	The Navajo Nation* Foote Mineral Company**	1,200,000
	Tuba City	The Navajo Nation* El Paso Natural Gas**	800,000
Colorado	Durango	Foote Mineral Company*	1,555,000
	Grand Junction	American Metals, Climax Div.**	1,900,000
	Gunnison	Gunnison Mining Co.**	540,000
	Maybell	Union Carbide Corporation*	2,600,000
	Naturita	Foote Mineral Company*	704,000
	Rifle (old)	Union Carbide Corporation*	350,000
	Rifle (new)	Union Carbide Corporation*	2,700,000
	Slickrock (UCC)	Union Carbide Corporation*	350,000
	Slickrock (NC)	Union Carbide Corporation*	37,000
Idaho	Lowman †	Porter Brothers*	90,000
New Mexico	Ambrosia Lake	Phillips 66* United Nuclear**	2,600,000
	Shiprock	The Navajo Nation* Foote Mineral Company**	1,500,000
Oregon	Lakeview	Atlantic Richfield Company*	130,000
Texas	Falls City	Susquehanna Western**	2,500,000
	Ray Point	Exxon, USA*	490,000
Utah	Green River	Union Carbide Corporation***	123,000
	Mexican Hat	The Navajo Nation* A Z Minerals**	2,200,000
	Salt Lake City	Vitro Corp. of America**	1,700,000
Wyoming	Converse County	Phelps Dodge Company*	187,000

***Property owned by Union Carbide but currently leased to the U.S. Air Force.

†No chemical processing was involved at this site. Heavy minerals in the dredge concentrate from placer deposits were upgraded by physical methods.

were Kerr McGee, Vanadium Corporation of America (VCA) and its successor Foote Mineral Company, in chronological order. The property contained in the site was located on the Navajo Reservation and leased from the Navajo Nation. In 1973, this site was returned to the Navajo Nation and the Navajo Nation requested assistance from the EPA through the PHS Indian Health Service. The Navajo Nation was using the site and structures to provide a heavy equipment operators school for the Navajo people.

The Navajo Nation requested the EPA to:

1. Determine the radiation exposures present.

2. Evaluate the exposures and determine if any health hazards exist.

3. Determine the various options for remedial action, if necessary.

4. Assist in planning the necessary program to achieve the option chosen.

5. Provide health physics expertise during the remedial action.

Thus, in cooperation with the Navajo Nation's Environmental Protection Commission, the Indian Health Service's Window Rock Area Office, and the State of New Mexico's Radiological Health Unit; the ORP Las Vegas facility responded to the request.

To date, the remedial action at the site is the largest decontamination effort ever undertaken. The area being decontaminated consists of about 350 acres and removal of tailings material varying in thickness from about 3 inches to 20 feet has been required. At completion (expected to be during 1977), the radiation exposures in the area involved will have been reduced to as near background as possible and the tailings material will be stabilized (interim stabilization) to prevent further erosion. Other remedial action may be taken after consideration of the Phase II report for this site.

Predicted doses

The necessity of any one of the possible remedial actions is based on predicted population exposures and the predicted health effects that would result in the exposed population. EPA has estimated the radiation doses to an individual and the population *(3.20,3.21)*. Table 3-2 presents the results for six inactive tailings piles.

Dose calculations have also been performed by Ford, Bacon & Davis Utah, Inc. and appear in the Phase II Vitro Report *(3.19)*. This report also contains the predicted health effects and cost/benefit considerations. The health effect referred to is a fatal lung cancer and the health benefit (health effect avoided) for the eight options considered varied from 2-25 health effects avoided for the first 25 years after remedial action. These increased to 13-490 by considering a 200-year period. The calculated cost/benefit for the options ranged from $20,000 to $60,000 per health effect avoided for the 200-year period *(3.19)*.

Table 3-2. Radiation dose rates for selected inactive uranium mill tailings piles *(3.20)*

Tailings pile	Dose to bronchial epithelium of critically exposed individual (mrem/y)	Aggregate lung dose rate to the population within 80 km (organ-rem/y)
Salt Lake City, Utah	14,000	70,000
Grand Junction, Colorado	8,100	14,000
Mexican Hat, Utah	1,200	660
Monument Valley, Arizona	140	2.5
Tuba City, Arizona	2,100	470
Shiprock, New Mexico	900	840

Phosphate Mining and Processing

The fact that uranium, thorium and radium occurred in phosphate rock throughout the world has been known for several years, but the information was primarily obtained for geological identification purposes. However, with the realization that radon from uranium mill tailings can cause significant exposures to the general public, these other sources of radon have come under scrutiny by health physicists. Initial field studies were performed by EPA in the Southeastern United States, primarily Florida since, as reported, 91 percent of the phosphate rock mined comes from Florida. Tennessee produces 3 percent, and the remainder comes from the States of Idaho, Missouri, Montana, Utah, and Wyoming. Phosphate deposits also occur in North and South Carolina and Georgia. The development of the deposits in North Carolina is now underway; however, no development is known to be underway in the other two States. The results of the field efforts have been reported by EPA *(3.2)*.

One of the first steps in processing phosphate ore in Idaho is roasting or calcining. Preliminary laboratory analysis indicated that during this process, about 85 percent of the naturally occurring polonium-210 volatilized. A field effort was started to determine the actual discharge levels and determine the effectiveness of certain control technologies.

Plants which process the phosphate rock are located throughout the United States; most produce fertilizer. In general, there are four types of facilities: (1) mines, (2) beneficiation, (3) phosphate milling and manufacturing, and (4) fertilizer production.

Mines

Two techniques are used, wet and dry mining. Wet mining is practiced in North Carolina and Florida; dry mining is used in Tennessee and most Western States *(3.22)*.

At a wet process mine, the ore is stacked in a suction well or sluice pot and high pressure water is used to produce a slurry which is pumped to a washer plant. The rock mined with dry mining techniques is transported to the beneficiation plant or mill by rail or truck.

Beneficiation

Much of the western phosphate rock can be used in mills without upgrading the P_2O_5 percentage. However, beneficiation by physical separation is necessary for most of the Florida and North Carolina ore *(3.22)*. The beneficiation process produces marketable phosphate ore and two separated wastes; slimes which go to a slime pond and sand tailings which go to a tailings pile.

Phosphate milling and manufacturing

The marketable phosphate rock can be processed by either of two types of facilities, a wet process phosphoric acid plant or an electric furnace plant.

The ground phosphate rock is mixed with 93 percent sulfuric acid and water in the wet process plant. Following this reaction in an attack vessel which produces phosphoric acid and gypsum, the mixture is filtered. The slurried gypsum is pumped to a pile near the facility when it is allowed to dewater. The phosphoric acid can then be used to produce two other major products, triple super phosphate and ammonium phosphate fertilizers:

Filter phosphoric acid + ammonia → ammonium phosphate

Filtered phosphoric acid + marketable phosphate rock → triple superphosphate

An electric furnace plant utilizes phosphate rock, silica and coke to form elemental phosphorus. Ferrophosphorus and calcium silicate slag are also produced.

Fertilizer production

Fertilizers are produced to provide biologically available nitrogen, phosphorus, and potassium. Approximately 80 percent of the domestic-marketable phosphate rock is utilized to manufacture various types of fertilizers throughout the United States *(3.23)*. Thus, after the previously described mining and processing steps, thousands of different fertilizer formulations are produced to fit individual soil and crop needs from the building blocks of the fertilizer industry (superphosphates, phosphoric acid, potassium cloride and ammonium). Because of the bulk blending and mixing, it is impossible to determine the basic phosphate origin of a specific formulation once it has been mixed. This is unfortunate since, although the phosphorus content of a 10-10-10 fertilizer product made from different basic phosphate materials would be the same, the naturally radioactive decay chain product concentrations could differ greatly depending upon which basic phosphate material was used, as shown in table 3-3 *(3.23)*.

Radiation studies

In the United States, thorium and uranium concentrations in phosphate rock range from 2 to 19 ppm (0.4 to 4 pCi/g) and 8-399 ppm (5.4 to 267 pCi/g), respectively *(3.22)*. The highest and lowest concentrations were reported in South Carolina and Tennessee, respectively. In general, higher concentrations are associated with marine deposits. It has also been shown that, as with other ore such as uranium, the uranium or

Table 3-3. Natural radioactivity concentrations in Florida phosphate ore, waste, and fertilizer materials *(3.23)*

Material	Concentrations (pCi/g)			
	^{226}Ra	^{238}U	^{230}Th	^{232}Th
Marketable rock	42	41	42	0.4
Slimes	45	44	48	1.4
Sand tailings	8	5	4	0.9
Normal superphosphate	21	20	18	0.6
Diammonium phosphate	6	63	65	0.4
Concentrated superphosphate	21	58	48	1.3
Monoammonium phosphate	5	55	50	1.7
Phosphoric acid[a]	<1	25	28	3.1
Gypsum	33	6	13	0.3

[a] 29 percent acid

thorium and their daughter products exist in secular equilibrium, i.e. members of the same series will be present in equal activities. The mining and processing of the phosphate ores redistributes these naturally radioactive nuclides among the various products, byproducts, and wastes. Thus, the materials are dispersed throughout the environment.

At present, the wastes (slag, slime, gypsum, and overburden) are being evaluated to determine their radioactive contribution to the environment. Recommendations against the use of slag in building materials have been provided by the EPA to the State of Idaho. Some foreign countries use waste gypsum for the manufacture of wallboard, and this use is being studied. Although, no waste gypsum is presently known to be used in the manufacture of wallboard in the United States, samples of this product have been imported from other countries for laboratory analyses. Wallboard using byproduct gypsum was supposedly produced in the United States at one location during the 1940's.

Much of the land mined for phosphate has been reclaimed by replacing the overburden removed to reach the phosphate ore. Habitable structures built on this reclaimed land are now being evaluated in Florida. To date, measurements have been made in about 125 structures, two-thirds of which were believed to have been built on reclaimed phosphate land *(3.3)*. In general, the data from the Florida study coupled with existing information indicates that radium-226 concentrations in soil beneath structures significantly affects the radon daughter levels within the structures. The data collected suggests that structures built on reclaimed land have radon daughter levels significantly greater than structures built elsewhere.

The EPA is also investigating the radioactivity concentrations in the products and by-products of the phosphate industry, as well as the phosphate ore and waste. The concentrations that have been determined are shown in table 3-3.

The data presented by Guimond *(3.23)* indicated that as with other ores, the nuclides of the uranium-238 chain are in equilibrium; and the gross radioactivity balancing of the input ore and the output products of the "wet process" operations indicates that approximately 1 percent of the radium-226, 60-80 percent of the thorium-230, and 80 percent of the uranium-238 is dissolved during the acidulation by sulfuric acid *(3.2)*. This results in samples of phosphoric acid containing about 1000 pCi/ℓ of radium-226 and uranium-238 concentrations ranging from 50,000 to 100,000 pCi/ℓ *(3.24)*.

Some fertilizer is used in all 50 States, but 10 States (table 3-4) account for about 50 percent of the United States fertilizer consumption. Potash fertilizers are not consumed at the same rate in each State because of the varying soil conditions. The 10 major potash-consuming States are shown in table 3-5; however, the 3 largest potash-consuming States, Illinois, Iowa and Indiana are also among the largest phosphate fertilizer-consuming States.

Soluble nutrients and elements such as nitrogen, carbon, and sulfur are generally recycled to a large degree in the biosphere. Other elements, such as phosphorus and potassium, which lack a naturally-occurring gaseous phase, must be continuously renewed since they do not have a complete cycle. These elements, if not intercepted by plants or held by soils, have a one-way journey to the sea, although some fraction of them may be deposited in river beds and other land during the journey. This is also the fate of many trace materials such as the various radionuclides that are incorporated with potassium and phosphate nutrients *(3.25)*. Thus, in the United States, the greatest amount of radioactivity from agricultural runoff is probably received by the Mississippi River Basin (table 3-6) *(3.23)*.

The potential uptake of the radionuclides by plants provides the exposure pathway for these radionuclides present in fertilizer. Potassium is homoestatically controlled in the body; thus, the uptake of ^{40}K should not be as variable as the uptake and subsequent impact of the naturally-occurring radionuclides. Therefore, the phosphate fertilizers are of primary interest.

The present knowledge about the uptake, the various nuclides, and the parameters that affect the uptake makes it difficult to quantify the national impact from the uptake of radionuclides in the food supply due to fertilizer use, but the radioactivity content of various fertilizer "building blocks" could be used to minimize any potential impact. As can be seen in table 3-7, a fertilizer with a phosphoric acid base would contribute the least radium-226, which would also be the least radium per gram of P_2O_5. The fertilizer made with normal superphosphate (table 3-7) would contribute the most *(3.23)*.

Table 3-4. Estimated radioactivity distribution in the major States using phosphate fertilizers during 1974 *(3.23)*

State	Consumption ($\times 10^3$ MT P_2O_5)	Quantity (curies)		
		^{226}Ra	^{238}U	^{230}Th
Illinois	432	15.1	108	111
Iowa	360	12.6	90	93
Texas	269	9.4	67	69
Indiana	265	9.3	66	68
Ohio	246	8.6	61	63
Minnesota	243	8.5	60	63
Missouri	172	6.0	43	44
Kansas	162	5.7	40	42
California	161	5.7	40	41
North Carolina	142	5.0	35	37
Total United States	4657	163	1160	1190

Table 3-5. Estimated radioactivity in the major States using potash fertilizers in 1974 *(3.23)*

State	Consumption ($\times 10^3$ MT K_2O)	^{40}K (Ci)
Illinois	549	382
Iowa	417	292
Indiana	366	255
Minnesota	293	204
Ohio	281	196
Wisconsin	246	172
Georgia	220	153
Florida	210	146
Missouri	197	137
North Carolina	185	129
Total United States	4610	3214

Table 3-6. Estimated radioactivity present in phosphate fertilizers used during 1974 in States bordering the Mississippi *(3.23)*

State	Consumption ($\times 10^3$ MT P_2O_5)	^{226}Ra (Ci)	^{238}U (Ci)	^{230}Th (Ci)
Illinois	432	15.1	108	111
Iowa	360	12.6	90	93
Minnesota	243	8.5	60	63
Missouri	172	6.0	43	44
Wisconsin	127	4.4	32	33
Kentucky	102	3.6	25	26
Tennessee	87	3.0	22	22
Mississippi	79	2.8	20	20
Arkansas	73	2.6	18	19
Louisiana	65	2.3	16	17
Total	1740	61	434	448

Table 3-7. Relative radioactivity of phosphate fertilizers *(3.23)* (pCi/g P_2O_5)

Phosphate fertilizer	^{226}Ra	^{238}U	^{230}Th	^{232}Th
Normal superphosphate	112	107	95	3
Concentrated superphosphate	44	121	100	3
Diammonium phosphate	12	137	141	1
Monoammonium phosphate	10	115	104	3
Phosphoric acid	3	169	188	21

Additional exposure pathways being examined include external gamma radiation exposure. Umwelt *(3.26)* has estimated that 0.11 mrad/y could occur to the gonads and bone marrow from one field application of phosphate fertilizer. By utilizing a fertilizer application period of 80 years, he calculated that an individual member of the population could have received 1.7 mrad/y and agricultural workers, about 2 mrad/y.

In addition, an inhalation pathway exists and exposures to airborne particulate nuclides and radon daughters could result. The highest potential exposures in this pathway are believed to occur to phosphate industry workers since they can come into contact with large amounts of phosphate ores, products, and wastes. Windham *(3.27)* estimated the direct gamma dose equivalent for these workers to be 10-300 mrem/y and a maximum dose equivalent through inhalation of 6 rem/y.

Thorium Mining and Milling

The commercial production of thorium in the United States has usually been from monazite sands, but a list of facilities has not been compiled nor made available to EPA; thus, thorium mining and milling operations have not yet received extensive study. One, now inactive, operation in Salmon, Idaho, was surveyed during the 1971 EPA mobile and field team gamma evaluations. No use of the waste material from this operation was discovered.

A decontamination effort of a thorium processing facility is planned by ERDA for 1977; thus, information about specific problem areas may be available soon.

Radon in Potable Water Supplies

Ingestion pathway

When a person obtains a glass of water from a consumer use point such as a tap or faucet, any radon remaining in solution is ingested. The maximum permissible concentration (mpc) for ingestion of radon in water is 2000 pCi/ℓ as published in NBS Handbook 52, *(3.28)*. This value was later considered conservative because it did not reflect the fact that the bulk of the alpha energy is absorbed in the gut contents. Recommended mpc's are absent from later compendia such as the Rules and Regulations of the Atomic Energy Commission *(3.29)* and the Recommendations of the International Commission on Radiological Protection *(3.30)*, but there is literature on the dose from radon ingestion *(3.31-3.38)*. In these studies the stomach, the whole body, the liver, the kidneys, fat and marrow have been considered as critical organs. The organ receiving the largest dose is the stomach where the dose to the walls has been estimated to range from 0.24 to 0.44 mrem/nCi ingested (Q.F.=10), depending upon whether the stomach is full or empty at the time of ingestion *(3.37)*.

Inhalation

If the domestic water containing radon is heated, as in cooking; aerated as in a shower or dishwasher; or agitated, as in hand dishwashing or clothes washing machines; the radon should readily diffuse from the water into the home atmosphere. Once in the atmosphere, radon daughters are formed by decay and are available for inhalation by the occupants of the home.

Initial calculations using a radon in water concentration of 500 pCi/ℓ; a radon daughter equilibrium ratio of 1:0.9:0.5:0.35; a complete air change each hour; other parameters as detailed by Gesell, et al. *(3.39)*; and a dose conversion factor of 0.25 WLM/y equal to a maximum dose of 4 rem/y at 60 μm depth in a 5th generation bronchus produced a rather large person-rem exposure (5 x 10^5). Further considerations of the BEIR report *(3.40)* indicated that about 20 health effects per year could result per 10^6 persons exposed. This prompted the need for a more exhaustive literature survey.

Review of radon-222 in ground water

Radon exists in ground water at concentrations which are typically much greater than its immediate precursor, ^{226}Ra. This occurs because radon, as a noble gas, is freer to migrate into water than radium in the rocks, sands and clays which make up aquifers. Furthermore, the daughters of radon typically occur at concentrations much lower than equilibrium values, presumably because their chemically active nature allows them to plate out upon the surfaces of the aquifer. Investigations have been made of radon in water for a variety of purposes, including fundamental geological and geochemical investigations, mineral prospecting and public health. More recently associations have been suggested between radon in certain natural waters and seismic activity so it is likely that more data will become available as various seismic research groups publish their findings.

Seven sources of data on radon in water were examined. Areas of the United States covered were North Carolina *(3.41)*, Maine *(3.42)*, Houston, Texas *(3.43)*, Western United States *(3.44)*, Hot Springs, Arkansas *(3.45)*, environs of Great Salt Lake, Utah *(3.46)* and South Texas *(3.47)*. A variety of analytical methods were used. The data from each report were ploted as frequency distributions and compared. The distribution of data for drilled wells in Maine *(3.42)* indicated very much higher radon levels than the other areas. Rather than present individual figures for each area, the available U.S. data (438 samples) except for Maine have been combined into a single frequency distribution, figure 3-1. Seventy-four percent of the ground water sources represented here fall between 0 and 2000 pCi/ℓ with 26 percent above 2000 pCi/ℓ, and 5 percent above 10,000 pCi/ℓ. Many but not all of the samples were taken in areas which were thought by the investigators to be high in natural radioactivity so the distribution is not representative of the entire U.S. ground water supply *(3.48)*.

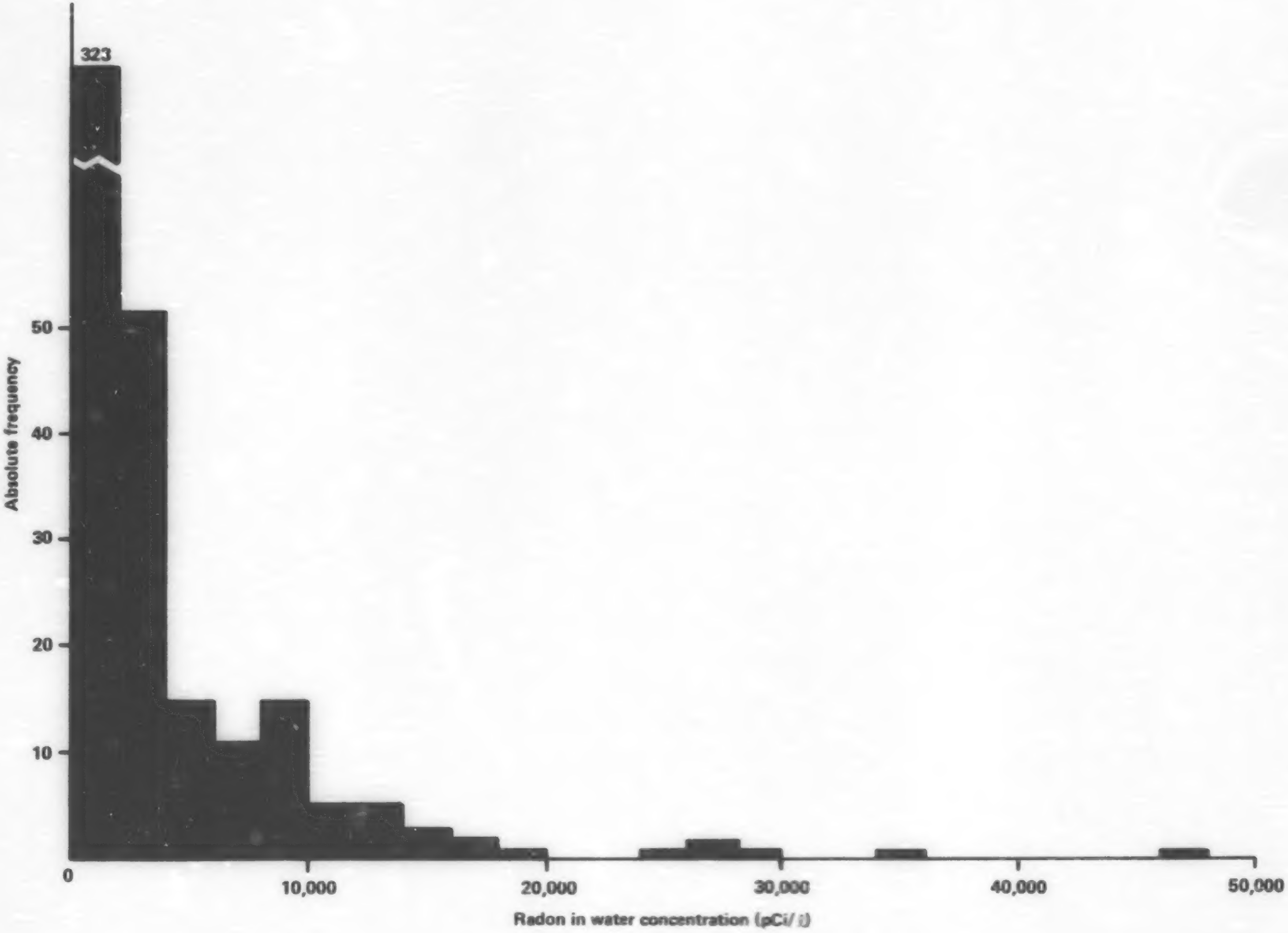


Figure 3-1 All United States radon in water concentration data except New England States (438 samples,

Additional samples (69) have now been obtained by EPA from Polk County, Florida. Thus, the U.S. data (excluding the Northeast) now contains 507 samples and the adjusted percentages indicate 75 percent of the samples contain less than 2000 pCi/ℓ. Five percent still exceeds 10,000 pCi/ℓ.

The data reported from Maine in Smith's report *(3.42)* were not radon concentrations. However, the complete scientific report of the project on which Smith's paper was based was located and radon concentrations were reported *(3.49)*. This data includes 224 samples from Maine and 32 samples from New Hampshire. Although not as high as originally believed, the Northeastern U.S. data are higher than radon concentrations reported for the rest of the United States: 56 percent exceed 2,000 pCi/ℓ, 24 percent exceed 10,000 pCi/ℓ, and 2 percent exceed 100,000 pCi/ℓ (figure 3-2).

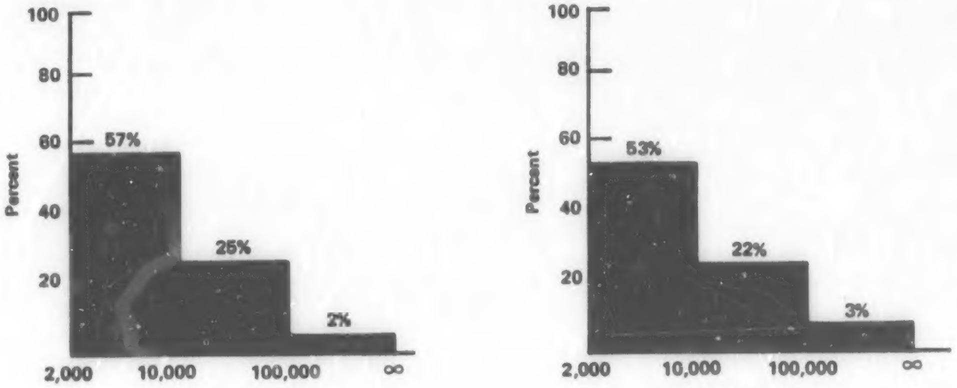
Discussion

The studies reviewed give a very general idea of the range and distribution of radon in ground waters. With few exceptions, however, the data do not lend themselves to direct interpretation in terms of public health. This occurs for several reasons. The studies which were geologically motivated did not confine their sampling to sources of potable water and even the health-motivated studies usually reported wellhead values rather than distribution system values. Furthermore, almost all the studies began with prior knowledge of radioactivity in the areas studied. In addition, there is incomplete geographic coverage of the United States. Thus, it would be risky to generalize from the existing data to the entire population. What is clearly apparent from the data is the fact that some potable ground waters contain measurable quantities of radon and that high, and in some cases extremely high, concentrations of radon exist in waters used for domestic supplies. The extent of the occurrence of these very high values is not known at this time. The effect of treatment and distribution on radon levels in finished drinking water is also unknown.

Limited field studies

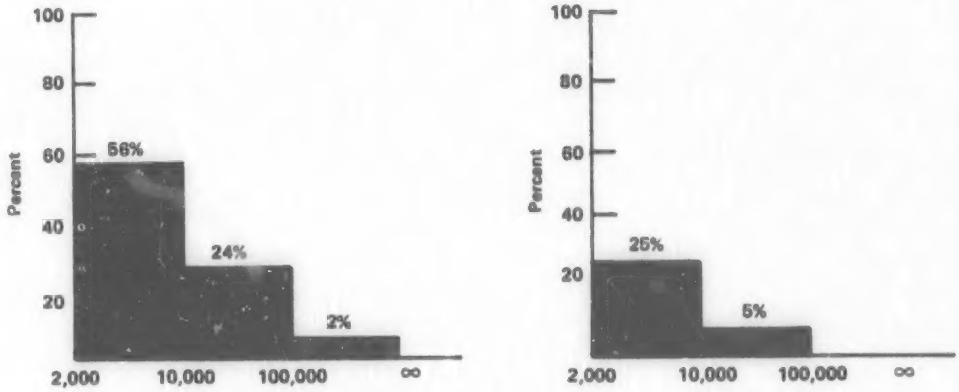
As the literature demonstrates, the domestic water used in a household may contain radon. However, a radiation exposure to the occupants will not result if the radon does not diffuse from the water; or if the radon does diffuse, but the radon - radon daughter equilibrium is kept low by increasing the number of air exchanges within the home.

In order to determine if the radon in the water does diffuse into the air and to determine the amounts that might be expected to diffuse, shower and tub experiments were performed by Gesell in Houston and south Texas *(3.43)*. The Houston, Texas, experiments are shown in figure 3-3. The volume of the bathroom used in Houston was 6.65 m^3 (including the shower). A shower curtain was used, allowing for air circulation in the bathroom while the shower was in use. The flow rate for both Houston shower experiments was 13.4 ℓ/min.



Maine
(244 Samples)

New Hampshire
(32 Samples)



Northeastern U.S.
(256 Samples)

Other U.S.
(507 Samples)

Figure 3-2. Percent of samples exceeding indicated radon-222 concentrations

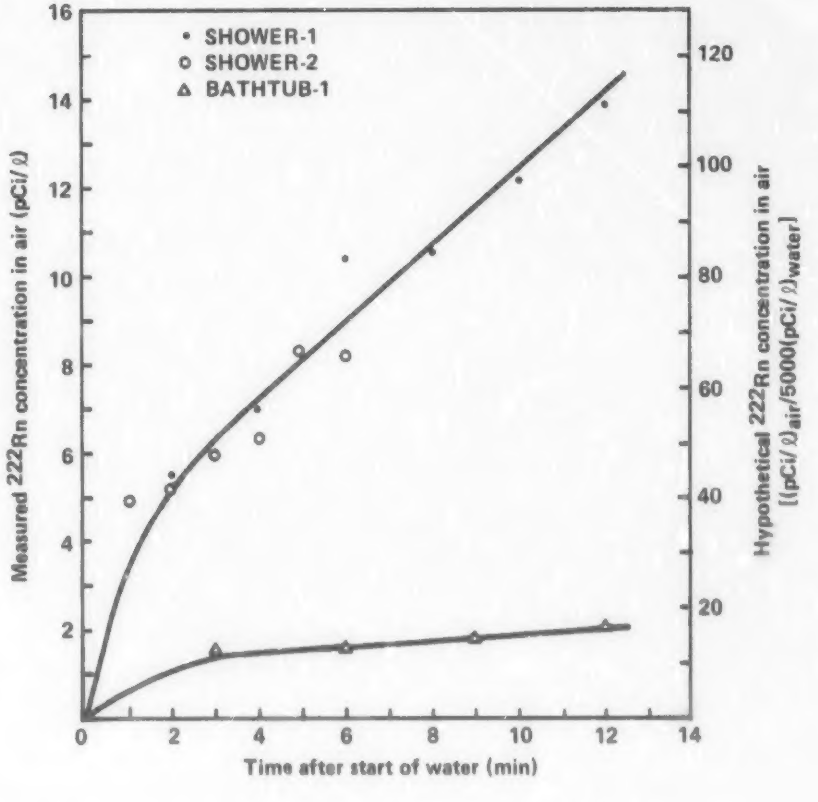


Figure 3-3. Houston, Texas. Radon water-air transfer efficiency experiment

During the first "wet" run, the radon in water concentration was 634 pCi/ℓ. Thus, during the 12 minute flow time, 1.02×10^5 pCi radon were available. If all the available radon diffused into the air, the air concentration would have been 15.3 pCi/ℓ (assuming negligible decay in 12 minutes). The actual measured air level (less a background of 0.5 pCi/ℓ) was 13.4 pCi/ℓ.

During the second run, the water flowed for 6 minutes; the radon concentration was 677 pCi/ℓ and the total available radon was 5.44×10^4 pCi. If all the radon diffused, the air concentration would have been 8.2 pCi/ℓ. The measured concentration (less the 0.5 pCi/ℓ background) was 7.7 pCi/ℓ.

In both the shower and tub experiments, the radon was collected in scintillation cells (Lucas cells) and subsequently counted. The bathroom volume for the Houston tub experiment was 11.9 m^3, and 50 liters of water were added to the tub. The radon concentration was 730 pCi/ℓ. The 3.65×10^3 pCi of radon in the water, if completely diffused, would have produced an air concentration of 3.1 pCi/ℓ. The radon concentration was still increasing after 15 minutes, but there were not enough scintillation cells to continue sampling.

The bathroom volume in the south Texas experiment was 10.9 m^3, and 50 liters of water with a radon concentration of 17,200 pCi/ℓ were added to the tub. Since the 8.6×10^5 pCi of total radon that was available could only have produced an air concentration in the bathroom volume of 78.9 pCi/ℓ, the data in figure 3-4 might indicate that another source of radon was available; either an undetected source (not likely since the background measurement was 1.7 pCi/ℓ) or for some reason more radon entered in the water. The most likely reason for the inconsistency is that there was not complete air mixing in the bathroom since the samples were collected directly over the tub water at sitting-head height.

The bathroom is obviously only a small fraction of the total volume of a normal house (approximately 200 m^3). Figure 3-5 serves to indicate the type of air concentrations that would be expected in a house with different radon concentrations in water; complete house air turnovers of 1/2, 1, and 2 changes per hour; daily water consumption of 1 m^3; and a radon water-air transfer efficiency of 0.5 for all uses. Under these assumptions, radon in water can make substantial additions to the average background indoor radon concentration of (0.1-0.5 pCi/ℓ).

One experiment has also been performed in Florida in a house that was built on reclaimed phosphate land *(3.50)*. The radon concentration in the bathroom was 30.9 pCi/ℓ which was determined to be the ambient level. After running the shower for 10 minutes, the level in the bathroom was determined to be 46.6 pCi/ℓ. Equipment to determine the radon concentration in this water was not available. A rough calculation indicated a concentration of about 400 pCi/ℓ.

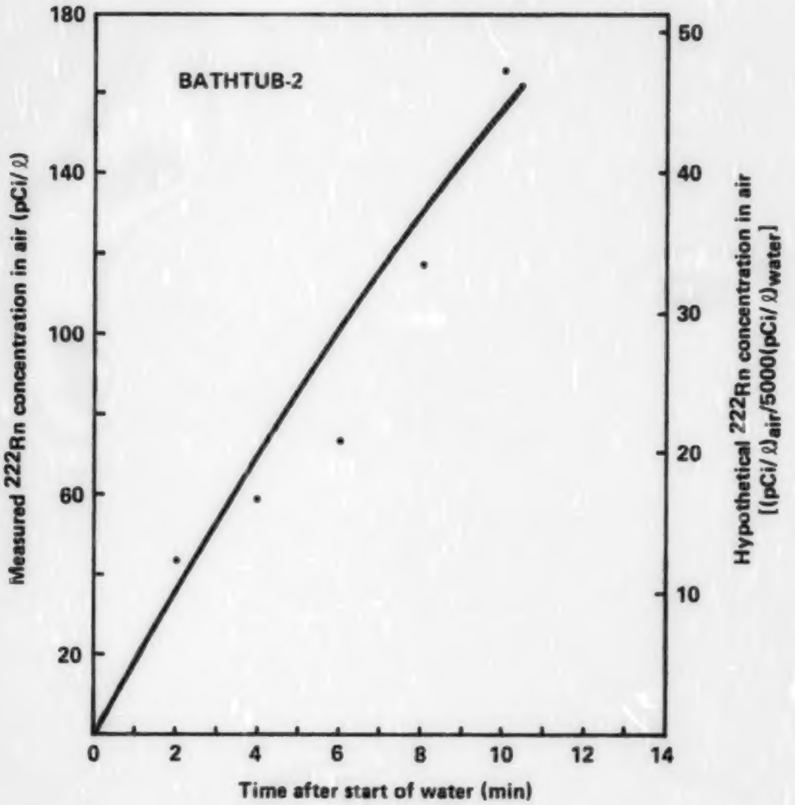


Figure 3-4. South Texas. Radon water-air transfer efficiency experiment

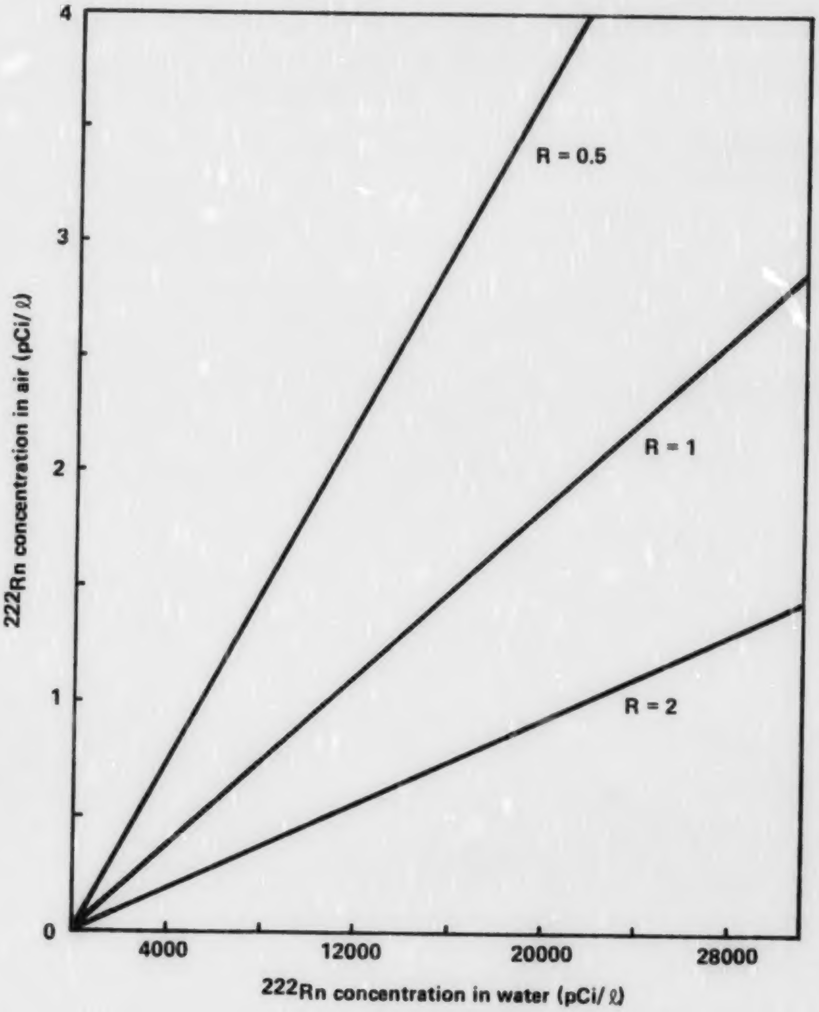


Figure 3-5. Estimated radon in air

Additional data from Texas has now been collected by Gesell *(3.51)*. Simultaneous indoor and outdoor radon concentrations have been collected using an apartment in Houston. The radon concentrations determined for the apartment during a period when the apartment was vacant were 0.7-0.8 pCi/ℓ (indoor range 0.5-1.0 pCi/ℓ) and the outdoor radon concentration was 0.2-0.3 pCi/ℓ.

The sampling was continued when the family returned from vacation. The family returned about 1530 (3:30 p.m.) when the radon concentration was 0.6 pCi/ℓ inside the apartment. The radon concentration began to increase and reached 2 pCi/ℓ by 2300 and then decreased to about 0.7 pCi/ℓ by 0400-0700. At about 0800, the radon levels again increased reaching a peak of 2.4 pCi/ℓ about 1300. The radon then decreased to 1.7 pCi/ℓ by 1600 and again increased to 2.2 pCi/ℓ about 2200.

The radon sampling was continued for a 15-day period and the concentrations observed at the same time on each day were averaged. The resultant averages are shown in table 3-8. The average radon concentration during the period studied was 1.2 pCi/ℓ.

Table 3-8. Average indoor radon concentration for a 16-day period in Houston, Texas (December 1976-January 1977) *(3.51)*

Time (24 hours)	Radon concentration (pCi/ℓ)	Time (24 hours)	Radon concentration (pCi/ℓ)
0500	0.8	1700	1.4
0700	0.7	1900	1.35
0900	0.9	2100	1.5
1100	1.1	2300	1.6
1300	1.3	0100	1.3
1500	1.4	0300	0.9

These data are the first experimental evidence that radon in potable water does cause an increase in the indoor radon levels in a structure. The radon concentration in the water is 1,600-2,000 pCi/ℓ, but the actual water usage has not been measured.

Summary and conclusions

The usefulness of this set of radon-in-water data obtained from the literature as a starting point for assessing the public health implications of this source of radiation exposure is limited by a number of factors. The accuracy of the individual measurements, the sampling strategy, the number of samples, and the source of the samples are important. Most of the data obtained for geochemical reasons were gathered from wells and springs irrespective of whether or not the water was potable. Much of the data gathered for public health reasons was obtained from wells rather than from distribution systems or house taps.

Based on the limited data in the United States, the distribution and range of reported radon concentrations in water is 0-30,000 pCi/ℓ with 25 percent of the locations exceeding 2,000 pCi/ℓ and 5 percent exceeding 10,000 pCi/ℓ. In granitic areas, the concentrations may be an order of magnitude higher. A large annual variation is not expected in a water supply, and radon concentrations could decrease due to decay or other loss between a water plant or wellhead and a consumer use point.

The ingestion pathway for radon has been studied and most authors consider dose to the stomach as the limiting dose. If 2 liters of water containing 10,000 pCi/ℓ are ingested daily, a dose of 25 mrem/week is delivered to the stomach *(3.35)*. However, the calculations presented (figure 3-5) indicate the same 10,000 pCi/ℓ in water could result in an air concentration of 1 pCi/ℓ *(3.48)*. The continuous inhalation of the radon-daughters (1:0.9:0.5:0.35) from 1 pCi/ℓ of radon could result in a dose to the bronchial epithelium of 80 mrem/week (4 rem/y).

To examine this hypothesis, the following assumptions previously determined by EPA were used *(3.39)*:

1. House size = 227 m^3 (8,000 ft^3)

2. Bathroom size = 6 m^3 (200 ft^3) (5 ft. x 5 ft. x 8 ft.)

3. Ventilation rate = 1 complete change each hour

4. Radon to radon daughter equilibrium in house = 50 percent

5. Continuous exposure to a radon concentration of 1 pCi/ℓ produces 4 rem/y and 1 working level month (WLM) per year ≅16 rem/y.

If the potable water being used in a dwelling contains 500 pCi/ℓ, the resultant ^{222}Rn air concentration could be 0.15 pCi/ℓ. The continuous exposure to this concentration could produce 500 mrem/y to the bronchial epithelium. Calculations on lung cancer fatalities based on the BEIR Report *(3.40)* indicate an estimated 20 health effects per year (fatal lung cancers) per 10^6 persons exposed to these hypothetical conditions. However, there are many unknowns in the hypothetical exposure conditions; thus, it must be remembered, these are only estimates and are presently unsubstantiated. Further efforts are being made to evaluate this potential exposure source.

Radon in Natural Gas

Natural gas as a source of radon and cause of subsequent population exposures to consumers has been evaluated by the EPA *(3.52)*. The EPA paper reviews data collected by many authors including Bunce, Barton, Faul and Gesell *(3.53-3.57)*.

Radon in the geological strata in which the gas wells are located diffuses with the natural gas into the wells, and various modes of storage and distribution were considered. These included wellhead concentration, well production rate, pipeline sources (gas from one area mixing with another area), transmission time, and storage time.

Doses to the bronchial epithelium were calculated assuming that the radon concentration in the gas was 20 pCi/ℓ, that 0.765 m^3 of gas was used in a kitchen range, in a 226.6 m^3 house with one air change per hour. The average air concentration was calculated to be 0.0028 pCi/ℓ and the tracheobronchial dose from unvented stoves and space heaters was calculated to be 15 and 54 mrem/y, respectively (table 3-9). The total for the United States was calculated to be 2.73 million person-rem per year *(3.52)*.

Radon in Liquefied Petroleum Gas

Most of the natural gas from well production fields is not distributed directly to consumers. It is first processed to remove impurities and the heavier more valuable hydrocarbons. Methane is the principal constituent of the natural gas. The components ethane, propane and other heavy hydrocarbons are bottled under pressure as liquefied petroleum gas (LPG) with propane as the major constituent. This process may remove from 21 to 96 percent of the radon in the natural gas *(3.58)*.

The exposures estimated in the EPA report, Assessment of Potential Radiological Population Health Effects from Radon in Liquefied Petroleum Gas *(3.39)*, for unvented kitchen ranges and space heaters were 0.9 and 4.0 mrem/y, respectively; 20,000 and 10,000 person-rem/y, respectively or about 30,000 person-rem/y would result (table 3-9).

Radon Daughter Exposures in Natural Caves

The possibility that natural radioactivity might present a hazard to people entering caves was first mentioned in 1968 *(3.59)*. Since that time, several articles have been written about the problem and data collected in various caves have been published *(3.60-3.68)*. The results suggested a possible health hazard for National Park Service (NPS) cave employees under an EPA standard which is enforced by the Occupational

Table 3-9. Estimated radiological impact from the combustion of natural gas and liquefied petroleum gas in unvented appliances (*3.52*)

Source of radiation impact	Critical nuclide	Dose to critical organ (mrem/y)		1970 population at risk ($x10^6$)	Population dose (person-rem/y) ($x10^6$)	Estimated health effects*
		Max indiv	Avg indiv			
Natural gas	Radon-222 +daughters	tracheobronchial tissues				
Unvented kitchen ranges		1,125	15	125	1.87	
Unvented space heaters		4,250	54	15.8	0.854	
Combined usage			69		2.73	15/y
(range)					(0.38-2.73)	(15-109/y)
Liquefied petroleum gas (LPG)	Radon-222 +daughters	tracheobronchial tissues				
Unvented kitchen ranges		50	0.9	21.3	0.02	
Unvented space heaters		650	4.0	2.8	0.01	
Combined usage			4.9		0.03	<1/y

*Health effect referred to is a fatal lung cancer.

Safety and Health Administration (OSHA). This standard, the uranium mining radiation exposure standard, sets a limit for exposure to radon daughters for uranium miners of 0.3 WL. The NPS is currently determining the radon and thorium concentrations in all the NPS-administered caves in which tours for visitors are regularly conducted *(3.68)*.

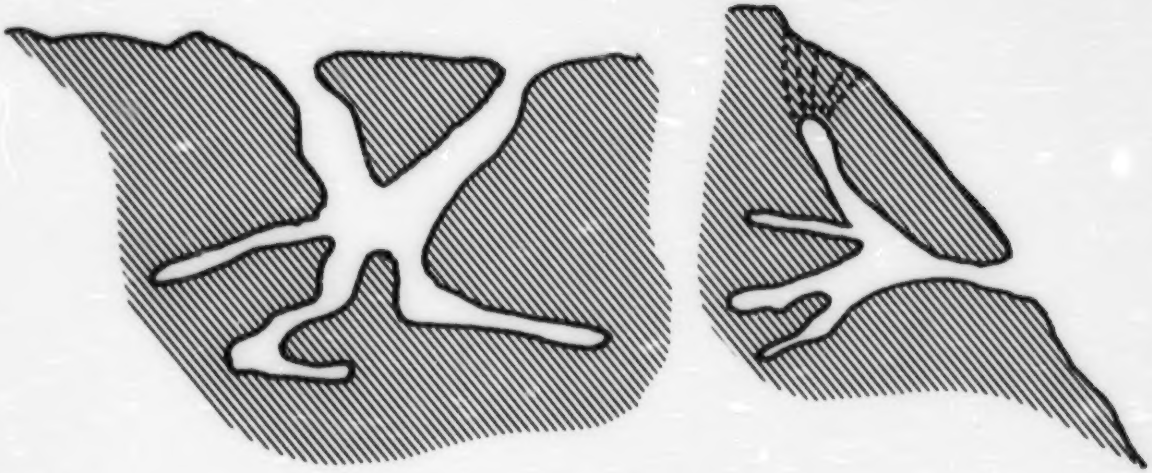
These caves are usually characterized by relatively uniform interior temperatures during the year. Thus at times, usually during the winter, there will be an interchange of interior air with outside air, and the radon concentrations in the cave will be diluted with outside air. During the summer, the outside temperature will probably be higher than inside and very little air exchange should occur. Thus, during the summer when visitor use would be expected to be the greatest, the working level (WL) exposure is also estimated to be the highest. However, use of elevator shafts, etc., could cause different effects.

The data plots prepared by the NPS suggest seasonal variations and based upon the initial data obtained they hypothesize that, "all caves having minimal manmade disturbances (such as tunnels, elevator shafts, bore holes, sealed and closed gates, etc.) which would alter the natural cave airflows experience seasonal variations ... increase in summer but decrease in winter, based upon natural air movements through the cave system." However, the fluctuations are not the same and actually depend upon the configuration of the cave and the cave's control of airflows. The NPS has identified two main cave configurations: (1) "Right-side-up" and (2) "Up-side-down" *(3.68)*. These may be envisioned by thinking of the "normal" cave (a flat surface and one decends into the cave which has tunnels at different depths or levels below the surface that are essentially horizontal). This cave would be "right-side-up." In a "up-side-down" cave, one enters below the cave level and actually goes up to tour the cave. Such a cave might be located inside a hill, bank, or mountain (figure 3-6).

These two types of caves produce different airflow patterns and; thus, different levels of radon and radon daughters result. If there is good airflow, the radon daughter concentrations will remain low; but if the air is stagnant which allows for radon daughter growth, the WL will be high. Therefore the pattern of airflow in all the NPS caves is being studied.

The thoron daughter levels measured have been very low (trace amounts) in all of the NPS caves. Thus, as in the other natural radioactivity problems investigated to date, alpha radiation from this source does not present a problem.

During the 3- or 4-hour underground visit, an individual's exposure will probably not be large; but a significant population person-rem per year may result because it is believed that an excess of one million persons visit some of the large caves operated by the U.S. National Park Service each year. The exposures received by NPS personnel are also being monitored.



A. "RIGHT-SIDE-UP" CAVE TYPE

B. "UP-SIDE-DOWN" CAVE TYPE

Figure 3-6. General cave configuration types determining natural airflows

If studies show that control methods should be instituted, ventilation would be envisioned as a corrective measure; however in this case, it is suspected that the control measure could eventually destroy the cave features and cave ecology that persons came to view. More work needs to be done on this source of possible radiation exposure.

Radon and Geothermal Energy Production

Energy from geothermal sources has been produced for several years at the Geysers Plant operated by Pacific Gas and Electric (PG & E) in Northern California. PG & E and the Union Oil Company of California have contracted with the Lawrence Livermore Laboratory (LLL) to determine the radon and radon daughters present in the production and waste streams of a geothermal electric power generator. Radon-222 concentrations in the thousands of pCi/ℓ have been mentioned in the waste streams, but the data have not been released to EPA.

It is projected that elevated exposures to radon and its daughters could occur at the plant and in the surrounding vicinity. Other environmental pollutants such as noise and toxic gases (hydrogen sulfide) are also associated with this industry.

Investigations of natural thermal areas and hot springs have recently been conducted by the EPA and others. As with the radon in potable water supply investigations, there has been no correlation observed between the radium and radon concentrations observed in the samples. Areas investigated to date are in the States of Arizona, California, Colorado, Idaho, Oregon, Nevada, New Mexico, and Utah *(3.44)*.

Radon Mines

Numerous former metal mine facilities in the Western United States were used as "treatment" centers at one time, advertising cures for gout, arthritis and various other physical complaints. Today, these facilities by law cannot advertise various cures and depend on testimonials from their clientele and word of mouth.

Surveys were carried out by the EPA and Montana Department of Health in several facilities in Boulder, Mont. During the usual "treatment" procedure, visitors descend into the mine and spend varying amounts of time sitting on benches or playing cards while inhaling the "curative" radon vapors. Some mines are supposedly "salted" with ore to ensure "helpful" radon levels.

The actual number of persons availing themselves of these facilities has not been tabulated, but the numbers would represent a small percentage of the entire population; thus, this source is not thought to produce a significant population dose.

Individual exposures are also limited because the visits to the mine are short (about 3 hours). Reportedly, most of the users come for a week's cure and, thus, would spend only 12-15 hours per year in the facility. However, workers at the facility such as receptionists and guides can receive significant exposure during their 40-hour week. In some cases, the working level month (WLM) exposures exceed the current uranium miner exposure standard of 4 WLM/y *(3.69)*.

Radioactivity in Construction Material

A literature search and discussion of reports of radioactivity in construction material has been prepared by the EPA's Office of Radiation Programs *(3.70)*. The report contains a bibliography of pertinent references that describe the exposure of the population to levels of the naturally occurring radionuclides present in construction materials.

EPA's bibliography on radioactivity in construction materials contains, to a large extent, articles from the early 1950's to the present, since few surveys were reported in the literature prior to 1950. A brief description of important topics dealt with in each article has been provided with the reference source for those articles which have been reviewed.

The summary from EPA's report follows:

"Surveys to determine the radioactive content of specific building materials used in the United States have not been reported in the literature. The external dose to the United States population from exposure to natural radioactive materials (exclusive of uranium mill tailings) contained in United States building materials has not been evaluated, and the possibly significant external exposure from the use of byproduct gypsum and fly-ash materials should be evaluated. The effects of various contruction materials on the attenuation of cosmic and terrestrial radiation have been evaluated in a limited number of surveys in the urban area of Boston, Mass., New York City, N.Y., and Livermore, Calif. The measurement of radon and radon daughter product concentrations has only been reported for a few dwellings and several multi-story office buildings in Boston and in several State-owned buildings in North Carolina. This literature search has found a lack of meaningful data for use in evaluating the U.S. population exposure from building materials."

Radioactivity in Fossil Fuels

Coal

Coal has long been known to contain traces of uranium which have been adsorbed onto the carbonaceous material during geologic periods *(3.71)*.

The magnitude of this deposition depends not only on the availability of coal, and uranium, but also on the presence of a medium by which the uranium can be brought into contact with the coal bed. Thus, uranium concentrations tend to vary between individual coal deposits, although in the United States, significantly higher (factors of 10 to 100) uranium concentrations in coal are generally found in the West (principally North and South Dakota, Montana, Wyoming, New Mexico, Idaho, and Nevada) as opposed to the eastern Appalachian deposits *(3.72)*.

As 70 percent of known U.S. coal reserves (45 percent by caloric value) are located in this western region, mining activity has steadily increased over the past few decades to its 1970 value of over 30 percent of total U.S. coal production *(3.73)*. This interest in the mining of western coal has gained impetus over the past few years due to the desulphurization requirements of the Clean Air Act (typically western coal entering the power plant is about a factor of 3 lower in sulfur than Appalachian coal *(3.73)* and the increased cost of fuel oil following the Arab oil embargo of 1973-74. With this interest in the large-scale utilization of western coal comes a concern over its potential radiological impact on the environment from airborne discharges, solid waste materials and ash utilization.

Few studies to date have been performed to determine effluent releases of radionuclides from power plants burning uraniferous western coal. Existing work has been concerned primarily with the geological occurrence of uranium in coal deposits and provides only source terms for various coal beds in the western region. Uranium concentrations cited for these western coal deposits range from 0.001 to 0.1 percent as compared to typical uranium concentrations in Appalachian coal of less than 0.001 percent *(3.72,3.74,3.75)*.

A few studies have been performed in the past to monitor radioactivity releases at selected fossil-fuel facilities burning Appalachian coal. The Environmental Protection Agency studied releases from the Tennessee Valley Authority's Widow Creek Power Plant in 1971 and the Oak Ridge National Laboratory studied releases from the Allen Steam Power Plant in Tennessee from 1971 to 1973. The overall conclusion of these limited studies was that the observed environmental levels did not constitute a significant public health problem. However, the power facilities investigated utilized low-activity eastern coal. According to Martin, et al. *(3.76)*, a modern coal plant would result in a maximum dose to the bone of about 0.1 mrem/y based on the following assumptions:

Size - 1000 MW(e)
Stack - 800 ft.
Stack (effective) - 1500 ft.
Particulate control - 97.5 percent removal
Fuel - eastern coal, 9 percent ash, .00004 percent uranium, and .00003 percent thorium
Radionuclides considered - ^{232}Th, ^{230}Th, ^{228}Th, ^{228}Ra, and ^{226}Ra
Population and meteorology of the Peach Bottom Power Station

From radioactivity release data provided in these and other studies, several authors have performed dose calculations. Bedrosian *(3.77)* calculated the total lung dose rate to individuals of the general population surrounding TVA's Widows Creek Steam Station to vary from 0.28 to 1.23 µrem/h (net values with background subtracted out) based on air samples analyzed from eight sampling stations. These figures are also comparable to values quoted by Martin, et al. *(3.76)*, based on additional measurements made downwind from the same power plant. In the latter case, the plant was of an older type with an inefficient particulate control system (less than 70 percent removal). Therefore, the doses calculated are likely to be higher than those comparably measured for newer, more advanced plants.

Using the measurements and calculations from these studies involving eastern coal, it is possible to extrapolate the dose levels to correspond to the higher radioactivity source terms of western coal. Existing data indicate there is a substantial abundance of such coal containing about .005 to .05 percent uranium. Therefore, based on the assumptions for a modern coal facility, it is estimated that burning these higher activity western coals could result in dose rates ranging from 4.4 x 10^{-3} mrem/h-MW(e) to 44 x 10^{-3} µrem/h-MW(e) for the longer and higher uranium concentrations, respectively. If it is assumed that these dose rates prevail for an annual period, then the nearby offsite individual dose to the bone ranges from 38 to 380 mrem per year for a 1000 MW(e) coal facility (table 3-10). Under the assumptions utilized, the bone was the critical organ; however, the lung is also an organ of major concern and modification of the assumptions could result in it being the critical organ. Regulations for nuclear power plants require that they be designed to limit offsite individual whole body dose to less than about 10 mrem/y.

There are several factors which could result in higher doses to the public than those estimated. First, western coal generally has a lower heating value than eastern coal (about 30 percent less) which would result in more western coal burned to obtain the same electric output. This may increase the dose estimates by about 30 percent. Second, the calculations of Martin, et al. *(3.76)* did not consider the dose contributions from the radionuclides, radon-222, short-lived radon decay products, and polonium-210. Since radon is a noble gas and polonium is a volatile material, both of these would probably not be effectively controlled by present particulate control equipment. Inclusion of these radionuclides in the calculations could substantially increase the lung dose estimates. Third, because of physical and chemical differences between eastern and western coal, there is some question whether present particulate control equipment would be as effective in plants burning western coal as those using eastern coal. Any reduction in particulate control efficiency would result in higher radiation doses to the public.

In addition to the radiation dose to the public that may result from stack emissions, there are several other pathways that may lead to potential population exposures (table 3-10). Runoff from mines and

Table 3-10. EPA-estimated radiological impact for a 1,000 MW(e) coal-fired electric station

Source of radiation impact	Critical nuclide	Dose to critical organ (mrem/y)		Population at risk (x10^6)	Population dose (x10^6) (person-rem/y)	Projected health effects
		Max indiv	Avg indiv			
Stack effluents						
Flyash						
Appalacian	^{226}Ra ^{230}Th (^{228}Ra, ^{228}Th, ^{232}Th)	65 (bone)	0.5-7 (bone)	50	0.03-0.35	1-11/y
Combined (includes western for 1985)		380 (bone)	5-70 (bone)	[a]50	.12-2	4-62/y
Gaseous (volatile)	^{222}Rn +daughters	(b)	(b)	(b)	(b)	(b)
	^{210}Po	(b)	(b)	(b)	(b)	(b)
	^{210}Pb	(b)	(b)	(b)	(b)	(b)
Mine runoff and drainage	^{226}Ra	[c]1.2x10^4	[c]1.2x10^3	.001	1.2	0.04/y
Runoff from flyash and bottom ash storage areas	^{226}Ra	(b)	(b)	(b)	(b)	(b)
Flyash in cement construction materials	^{222}Rn +daughters	[c]6.4x10^4 (lung)	[c]1.3x10^4 (lung)	[d].1	1.3	52/y
	^{226}Ra ^{232}Th	[c]400 (whole body)	[c]80 (whole body)	[d].1	.08	32/y 84/y
Large flyash and bottom ash piles-atmospheric radon contamination	^{222}Rn +daughters	[c]30 (lung)	[c]0.4 (lung)	[d]1	.4	0.4/y

[a] A population of 22 million is assumed exposed to stack effluents of western coal based on 44 percent of coal-fired plants being located near western coal deposits and therefore being potential users. The remainder of the 50 million (28 million) are assumed to be exposed to stack effluents of Appalacian coal with average uranium concentrations as noted under the "Appalacian" heading. The health effects calculated are based on a combination of the two respective average population doses.

[b] Data not available.

[c] For western coal only-on average, Appalacian coal approximately factor of 10 lower in concentration dose rate.

[d] Hypothetical exposed population.

acid mine drainage, for example, could increase radioactivity levels in surface and ground waters. Caldwell, et al. *(3.78)* performed an alpha radioactivity survey of the upper Kiskiminetas River, Pennsylvania, after noting periodically elevated radioactivity downstream. His survey showed that coal mine drainage into the river is the principal source of the radionuclides found, primarily ^{234}U, ^{238}U, and ^{226}Ra. The maximum gross alpha level measured was 164 pCi/ℓ downstream from a coal mine waste pile. Average gross alpha levels measured ranged from 11 to 13 pCi/ℓ.

Other potential pathways for radiation dose (table 3-10) to the public include:

1. Runoff from flyash and bottom ash storage areas which could increase radioactivity concentrations in surface and ground waters.

2. Construction materials such as cement, concrete, and block made from flyash which would present a potential lung cancer hazard due to elevated radon daughter levels in structures built from the materials.

3. Large flyash and bottom ash piles which could present a large radon-222 source that may cause elevated radon daughter levels in structures built near the piles and/or structures built on land reclaimed with flyash cover. A search of the literature did not identify any papers on these pathways, although models used in the ORP/EPA phosphate study may be applicable.

The individual and population doses due to coal combustion and byproducts therein are calculated from data found in the literature and/or models making use of various assumptions concerning source terms, effluent discharge rates and population exposed. An estimate of the potential health effects associated with these calculated doses is made for both Appalachian and western coals. The attached table summarizes these calculations, and also the assessment needs which outline what information remains to be collected and by what methods. The derivation of the values tabulated and further background on the assessment needs identified are discussed in the following sections.

Stack effluents

The primary exposures pathway to the population from power plants burning uraniferous coal is through inhalation. The critical radionuclides by virtue of their relatively long half-lives and their alpha energy are ^{226}Ra and ^{230}Th. There are two dose models in common use, with the lung and bone being the critical organs. The former is based on the insolubility of ^{226}Ra while the latter is based on the assumption of its solubility. The bone was chosen as the critical organ in these calculations because of the availability of pertinent data in the literature. Moeller *(3.79)* calculated an average bone dose equivalent rate to the population residing within a 16 kilometer (10 mile) radius of a

1000 MW(e) Appalachian coal-fired plant as being 0.5-7 mrem/y. This range was arrived at by using source term and dose data provided in reports by Martin, et al. *(3.76)* and Bedrosian *(3.77)*. The former calculated a maximum bone dose of 3.5 x 10^{-5} μrem/h MW(e) for a 1000 MW(e) power plant burning coal containing .00004 percent uranium, which when extrapolated for a maximum uranium concentration in Appalachian coal of .008 percent gives a nearby individual dose of 65 mrem/y. Western coal having an assumed average uranium concentration of .01 percent (.005-.05 percent) is approximately a factor of 10 higher than typical Appalachian coal. The average individual dose for western coal was calculated to be 5-70 mrem/y using this factor. The maximum individual dose of 380 mrem/y to the bone was determined by using the upper range of uranium concentration in western coal (.05 percent) as a factor to extrapolate from the Martin, et al. data.

The population at risk, 50 million, was taken from Moeller's draft notes on radioactivity in fossil fuels having derived this figure from published U.S. Congressional data. The 50 million population was broken down into two groups for the western coal population dose calculations; 44 percent or 22 million exposed to power plants burning western coal and 56 percent or 28 million exposed to plants burning Appalachian coal (table 3-10). The former represents a hypothetical population based on the percentage of the present fossil fuel plants that are situated adjacent to the western coal and lignite beds, which would be logistically more likely to utilize western coal. The population doses of 2.5 x 10^4 to 3.4 x 10^5 person-rem/y for Appalachian coal and 1.2 x 10^5 to 2 x 10^6 person-rem/y for western coal result in a health effect estimate of 1-11/y and 4-62/y, respectively. The health effects conversion utilized is 16 fatal effects and 16 nonfatal effects per 10^6 person-rem/y (bone dose) *(3.80)*.

Radon-222 and polonium-210 should be readily released through the combustive process of coal-fired plants. For man, the critical pathway for exposure is inhalation and the critical organ, the lung. Population dose information for these radionuclides are not available at this time.

Coal mine runoff and drainage

The only source of information identified in the literature was Caldwell, et al. *(3.78)* who provided gross alpha activity and ^{226}Ra concentration data for the Kiskiminetas River in Pennsylvania. The average bone dose (due to ingestion) of 1.2 rem/y was derived from an average concentration of 10 pCi/ℓ downstream from several coal mine runoff sites. This concentration is multiplied by a factor of 10 for the assumed increased concentration of uranium in western coals. The maximum value, in turn, corresponds to an average concentration of 100 pCi/ℓ, the upper range of their measurements. A hypothetical exposed population of 1000 was chosen which resulted in an average population dose of 1.2 x 10^3 person-rem and an estimated 0.04 health effects per year (assuming 16 fatal and 16 nonfatal health effects per 10^6 person/rem/y *(3.80)*.

Runoff from flyash and bottom ash

No literature was uncovered for this effluent category. In light of this, a determination of the number, size and location of such areas and their impact with the environment should be performed.

Flyash in cement construction materials

The radiological impact from cement construction materials utilizing flyash as a sand substitute is two-fold, stemming from: (1) inhalation of alpha-emitting radon daughters, a decay product of the radium-226 in the coal ash; and (2) gamma exposure due to the decay products. The average radon daughter exposure to the lung was calculated by Guimond *(3.81)*. Assuming a ventilation rate of 1 air change per hour and radon diffusion through 25 cm of material, the indoor radon daughter levels averaged 0.016 WL with a maximum of 0.08 WL. The hypothetical population at risk chosen by Guimond was 1×10^5, resulting in an average population dose of 1.3×10^6 person-rem and a health effect estimate of 52/y (assuming 40 health effects per 10^6 person-rem/y *(3.39)*.

The whole body dose due to gamma exposure from residential construction materials was estimated using a model developed by Feher, et al. *(3.82)*. In the original model, the external radiation burden was calculated for a room with an area of 20 m^2 using the following formula:

Dose Rate (mrad/y) = $K_{Ra}C_{Ra} + K_{Th}C_{Th} + K_KC_K$ where

K_{Ra}, K_{Th}, K_K = dose conversion coefficients for ^{226}Ra, ^{230}Th and ^{40}K in (mrad/y) (pCi/g).

C_{Ra}, C_{Th}, C_K = specific activities of ^{226}Ra, ^{230}Th and ^{40}K in a building material.

"K" values for three types of building material are provided in table 3-11. Although it is conceivable that coal ash could gain wide use in brick and adobe, concrete was chosen as the most widely utilized reference material. Assuming 1) an average ^{226}Ra and ^{232}Th concentration in western coal of 30 pCi/g for each; 2) that the ash is utilized in the concrete as a sand substitute at 20 percent by weight; 3) that the parameters as expressed in the preceding table hold true; and 4) that the difference between a 20 m^2 room and a 100 m^2 home can be approximated through the inverse square law; then the average individual exposure is expected to be about 80 mrem/y (whole body). The maximum individual dose is a factor of 5 higher than the individual dose (400 mrem/y), assuming that the difference is proportional to that between the maximum and average range of uranium concentration in western coals. With an estimated average individual dose of 80 mrem/y and a hypothetical exposed population of 1×10^5, a population dose of 8×10^3 person-rem was calculated leading to approximately 3.2 health effects per year (assuming 200 lethal and 200 nonlethal health effects per 10^6 person-rem, whole body *(3.80)*.

Table 3-11. Dose conversion coefficients for building materials

Type	Height (cm)	Thickness (cm)	Density (g/mℓ)	K_{Ra} [(mrad/y)/(pCi/g)]	K_{Th} [(mrad/y)/(pCi/g)]	K_K [(mrad/y)/(pCi/g)]
Precast concrete	250	14	2.5	22	32	2.5
Brick	280	38	1.7	26	36	2.8
Adobe	280	50	1.6	24	37	2.7

Large flyash and bottom ash piles--atmospheric radon contamination

With the indefinite storage of waste flyash and bottom ash from power plants, the uranium concentrations inherent in the ash, particularly that of western coal, may pose a potentially significant population dose. Utilizing computer modeling techniques developed by EPA/EAD and applied to calculate doses from by-product gypsum piles in Florida *(3.83)*, an average population dose was estimated using a factor of 10 increase for the uranium concentration in western coal. The average and maximum individual doses are calculated to be 0.4 and 30 mrem/y, respectively. With a hypothetical exposed population of 22 million persons (projected for 1985), a population dose of 9 x 10^3 person-rem/y was calculated. Assuming 40 health effects/y per 10^6 person-rem from ^{222}Rn, a health effect estimate of 0.4/y is made.

Oil

Oil, like coal, is a carbonaceous material which may absorb uranium. Studies by the U.S. Geological Survey *(3.84)* indicate that for the western crude oils investigated, the uranium content in the ash ranged from less than 0.0001 percent to 0.045 percent. The uranium content calculated as parts per billion in the crude oil ranged from 0.01 to 414.

Based on studies by Martin, et al. and the U.S. Atomic Energy Commission, Moeller *(3.79)* estimated that lung dose equivalent rates due to particulate emissions from a 1000 MW(e) oil-fired electric station to people living within 80 km would range between 2 and 40 mrem/y. This estimate has been used to calculate the population dose and resulting health effects from this source (table 3-12). It should be noted that no consideration is made for the dose contributions from radon-222 and

Table 3-12. EPA-estimated radiological impact for a 1,000 MW(e) oil-fired electric station

Source of radiation impact	Critical nuclide	Dose to critical organ (mrem/y)		Population at risk ($x10^6$)	Population dose (person-rem/y)	Estimated health effects
		Max indiv	Avg indiv			
Stack effluents	^{226}Ra ^{230}Th	0.04 (lung)	0.003 (lung)	5	15	$6x10^{-4}$
	^{222}Rn +daughters	*	*	*	*	*
Petroleum residues	^{222}Rn +daughters	*	*	*	*	*
	^{226}Ra	*	*	*	*	*

*Data not available

its short-lived daughters and polonium-210. However, because of the low overall radiological impact of the radionuclides studied, it is not anticipated that inclusion of these radionuclides would significantly increase the population dose.

The U.S. Geological Survey *(3.84)* also studied refinery residues for their uranium content. The uranium concentration of 16 refinery residues ranged from .0003 percent to .024 percent. They concluded that certain refinery residues could provide a source of by-product uranium. Since a large quantity of these residues are produced annually, the fate of the residues and their radiological impact should be more carefully ascertained through a limited literature evaluation.

Summary

Technologically enhanced natural radiation comes from radioactive material which occurs naturally; but man's technology either causes the material to enter man's environment, or allows people to enter a new environment. This occurs in mining where subsurface radioactive ores are brought to the surface of the earth; thus not only affecting workers in the industry, but potentially increasing the exposure of populations to these materials. Exposure to TENR would also occur in space or supersonic air travel. One of the most important of these exposures determined to date is from uranium mill tailings piles, the individual and population exposures of which are listed in table 3-2.

Phosphate mining and processing

Thorium concentrations in phosphate rock range from 0.4 to 4 pCi/g and uranium concentrations ranged from 5.4 to 267 pCi/g. The highest concentrations were reported in South Carolina. Much of the land mined for phosphate is reclaimed and is being used for home construction. These homes have radon daughter levels significantly higher than the levels in homes not built on reclaimed land.

Radon in potable water

Radon in water entering a structure will diffuse into the air and produce elevated radon concentrations inside the structure. The radon concentrations in water range from 0-30,000 pCi/ℓ in most areas of the United States sampled to date except for the Northeastern region, where the concentrations are an order of magnitude higher (0-300,000 pCi/ℓ).

Theoretical studies indicate water with a radon concentration of 500 pCi/ℓ could produce an estimated 20 health effects (fatal lung cancers) for every 1 x 10^6 persons exposed. Further, water with 10,000 pCi/ℓ could produce an excess air concentration of 1 pCi/ℓ, an estimated exposure of

4 rem/y per person, and an estimated 160 health effects for every 10^6 persons exposed. Actual data collected at one location indicate an elevated air concentration can result from water with a radon concentration of 2,000 pCi/ℓ.

Radon in natural gas

Burning natural gas with a ^{222}Rn concentration of 20 pCi/ℓ is predicted to give an average ^{222}Rn air concentration of 0.0028 pCi/ℓ and the tracheobronchial dose from this concentration could reach a maximum of 54 mrem/y. The total person-rem from this source is estimated to be 2.73 million person-rem/y.

Radon in liquefied petroleum gas

It has been estimated that unvented kitchen ranges and space heaters operating on liquefied petroleum gas would result in a population exposure of about 30,000 person-rem/y for the United States.

Radon daughter exposures in natural caves

Although individual exposures are not large, a significantly large population exposure could result due to the large population that visits natural caves.

Radioactivity from fossil fuels

Uranium concentrations in western coal range from 0.001 to 0.1 percent compared to concentrations in Appalachian coal of less than 0.001 percent. Dose rates from plants using western coal could be 0.0044 to 0.044 μrem/h-MW(e). If these dose rates prevail for an annual period, an exposure of 30-380 millirem per year could occur to individuals living offsite near a 1000 MW(e) coal-burning facility, assuming bone to be the critical organ. Population doses from radon-222 or polonium-210 (lung being the critical organ) are not available at this time.

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Chapter 4 - Fallout

This section presents the status of the collection and reporting of fallout data and doses to man from fallout for the year 1975. In those cases where there may be no data specific to the year 1975, data for doses for the latest year before 1975 are presented.

Information presented in this section of the report has been limited to those sources of information that are the most complete and up to date (re the year 1975). These sources are the Health and Safety Laboratory (HASL) fallout program reports and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report. The former provides an extensive source of fallout information in the form of raw data and interpretive comments. The latter provides the most comprehensive source of information on doses resulting from fallout although it is not current up to and including 1975.

Other sources of information on fallout monitoring and various reports on doses do exist; (see the ERAMS summary in this document) however, the inclusion of a discussion of each would be a laborious task which would provide little more information on fallout and doses than is contained in the sources selected for this report.

Health and Safety Laboratory Fallout Program

Every 3 months, the Health and Safety Laboratory (HASL) issues a report summarizing current information obtained at HASL pertaining to fallout.

To present a more complete picture of the current fallout situation and to provide a medium for a rapid publication of radionuclide and trace element data, the quarterly reports often contain information from other laboratories and programs, some of which are not part of the general ERDA program. To assist in the interpretation of the data, special interpretive reports and notes are included from time to time.

The reports are usually divided into four main parts which are:

1. interpretive reports and notes,
2. HASL fallout program data,
3. data from sources other than HASL, and
4. recent publications related to radionuclide studies.

An appendix to each quarterly report is also published. This appendix contains the results of the analyses of all samples taken under the HASL Fallout Monitoring Program.

Of the four main parts of the HASL reports only the second is fixed in regard to subject matter discussed. The other parts contain subject matter on various subjects as it becomes available. The second part, HASL Fallout Program Data, is comprised of information and data concerning the following fallout program subjects:

1) ^{90}Sr and ^{89}Sr fallout at world ground sites,

2) radionuclides and lead in surface air,

3) Project Airstream,

4) High Altitude Balloon Sampling Program,

5) ^{90}Sr in milk and tap water,

6) ^{90}Sr in diet (Tri-Cities), and

7) ^{90}Sr in human bone.

The ^{90}Sr and ^{89}Sr in monthly deposition at world ground sites activity consists of the collection of precipitation and dry fallout over monthly periods at stations in the United States and overseas. The samples are analyzed for ^{90}Sr and prior to 1971 for ^{89}Sr whenever possible. At present there are 35 monthly monitoring sites in the United States and 90 sites in other countries.

In late 1958 and 1959, the monthly fallout samples were analyzed for ^{90}Sr and ^{89}Sr. The ^{89}Sr measurements were discontinued in 1960 at most sites, resumed in September 1961 and discontinued again in 1971. Between May 1960 and September 1961, the monthly samples were combined on a 2-month basis because ^{90}Sr levels had dropped considerably. In September 1961, analysis of individual monthly collections were resumed.

The results of all analyses are published quarterly. All ratios of ^{89}Sr to ^{90}Sr have been extrapolated to the midpoint of the sampling month. Calculated values of the concentration of ^{90}Sr in precipitation are given in units of picocuries of ^{90}Sr per liter. The total precipitation in centimeters and the ^{90}Sr deposition in millicuries per square kilometer for data available in a calendar year are listed. The groups or organizations responsible for the sampling are identified. Monthly ^{90}Sr depositions for New York City since 1954 are shown in graphical form to reflect trends since 1954.

The HASL has been collecting surface air particulate samples at stations in the Western Hemisphere since January 1963. The sample filters are analyzed for a number of fission and activation product radionuclides as well as stable lead. The study is a direct outgrowth of a program initiated by the U.S. Naval Research Laboratory (NRL) in 1957 and continued through 1962. The primary objective is to study the spatial and temporal distribution of nuclear weapons debris and lead in the surface air. The present network of sampling stations extends from 76° north to 90° south latitude.

Samples are analyzed for concentrations of gamma-emitting radionuclides ^{7}Be, ^{95}Zr, ^{137}Cs and ^{144}Ce. Radiochemical analyses are conducted to determine concentrations of ^{54}Mn, ^{90}Sr, ^{109}Cd, ^{144}Ce, ^{238}Pu and ^{239}Pu. In samples collected after some French and Chinese atmospheric weapons tests, additional short-lived nuclides were analyzed, such as ^{89}Sr, ^{95}Zr, and ^{141}Ce. As the levels of any of the radionuclides drop to below practical detection limits they are eliminated from the radiochemical program. The results of all analyses (concentrations) are averaged for each month for each station from 1963 through 1975 by HASL.

Project Airstream is HASL's study of radioactivity in the lower stratosphere. An RB-57F aircraft serves as the sampling platform. Airstream missions are usually scheduled. The first Airstream mission was flown in August 1967.

The route followed by the sampling aircraft extends from 75° N to 10° S latitude. Air filter samples are collected at altitudes of 12-20 km along the flight track. A gamma analysis of the samples is made as well as detailed radiochemical analysis which includes some of the following nuclides; ^{89}Sr, ^{90}Sr, ^{210}Pb, ^{210}Po, ^{238}Pu, and ^{239,240}Pu. Results of the analyses are reported in HASL's "Fallout Program Quarterly Summary Report."

Under the HASL Fallout Program, HASL operates a High Altitude Balloon Sampling Program. Upper atmospheric nuclear debris are collected by balloon-borne filtering devices. The program has been in operation since 1957. Balloon flights were made in 1975 at altitudes from 21 km to 27 km from Alaska, New Mexico, and Panama.

The sampling filters from the balloon-borne samplers are analyzed for gamma activity as well as radiochemically for long-lived weapons-related radionuclides. These nuclides include ^{89}Sr, ^{90}Sr, ^{238}Pu, and ^{239}Pu. Starting in fiscal year 1973 and continued in fiscal year 1975 samples were also analyzed for ^{210}Pb, and ^{210}Po to compliment Project Airstream studies. The results of the sample analyses are published quarterly in HASL's "Fallout Program Quarterly Summary Report."

HASL has analyzed New York City milk and tap water on a monthly basis since 1954 to determine ^{90}Sr concentrations. Results are presented both tabularly and graphically and published quarterly. The graphical presentation describes the trends in levels since 1954.

HASL performs quarterly estimates of the annual dietary intake of ^{90}Sr of New York City and San Francisco residents. These estimates are based on the analyses of food purchased at these cities every 3 months since 1960. Available data are published in HASL's quarterly summaries.

HASL analyzes specimens of human vertebrae from New York City and San Francisco to determine ^{90}Sr concentrations. Human vertebrae specimens are also received, through the World Health Organization, from countries where western world-type diets are not typical. Analyses are published quarterly.

Interpretation of HASL fallout program data

Periodically, HASL publishes interpretive reports and notes concerning the data obtained from the fallout program. Generally, the reports and notes show the results of the last year's data and compare it to data from previous years. Occasionally, doses to man may be calculated. The following reports and evaluations were published by HASL for each of the indicated fallout program areas.

^{90}Sr and ^{89}Sr deposition at world ground sites

Each year since 1958 an estimate of the annual worldwide deposition and the cumulative deposit of ^{90}Sr, based upon data of the HASL sampling network, has been made. All of the primarily monthly precipitation and radiochemical data are listed and updated quarterly in the appendix to each HASL quarterly report. Additionally, a summary of these results, averaged over a 10-degree latitude band was published for 1975 *(4.1)*.

To determine worldwide deposition, HASL assumes that within the 10 degree latitude band, that HASL sampling sites, on the average, are representative of fallout in that area. Hence, multiplying the average monthly ^{90}Sr deposition (mCi/km^2) by the area of the latitude band (km^2) gives the total deposition in that band. For poleward areas beyond 80° N and 70° S, values of deposition are obtained by extrapolating a smoothly decreasing ^{90}Sr deposition to zero at the poles. Summing all the derived deposition in each latitude band yields the total worldwide deposition.

The total deposition of ^{90}Sr fallout on the earth's surface through 1975 was found to be 11.7 mCi *(4.1)*.

The total deposition of ^{90}Sr fallout on the earth's surface was estimated to be 92 kCi in 1975. In the Northern Hemisphere, the peak fallout occurred in the spring with 76 percent of the fallout being deposited between 20° and 60° N and 50 percent between 30° and 50° N. The highest fallout rate for the Southern Hemisphere occurred in the summer and early autumn (January-April) when 53 percent of the ^{90}Sr was deposited. Seventy-four percent of the total deposition in the Southern Hemisphere occurred between 20° and 50° south latitude *(4.1)*.

Figure 4-1 shows the annual cumulative ^{90}Sr deposition since 1958. The 1975 fallout rate in the Northern Hemisphere was about 50 percent of the 1974 rate and the worldwide rate was approximately 60 percent of the 1974 rate. The only year in which a lower deposition rate occurred was in 1973 prior to the Chinese atmospheric test in June *(4.1)*.

Table 4-1 presents the annual cumulative worldwide ^{90}Sr deposition, and cumulative ^{90}Sr deposition since 1958. From this table and figure, it is evident that the total ^{90}Sr burden is decreasing as radioactive decay exceeds fallout.

Strontium-90 in diet

Estimates of intake via the total diet in New York City and San Francisco have been made since 1960 based upon concentrations found in quarterly food samples. The dietary intakes of ^{90}Sr have decreased from maximum levels attained in 1963-64, but the decline has become more gradual in recent years due to the continuing small amounts of ^{90}Sr deposition and the little changing cumulative deposit in the soil.

The estimated annual intake in New York City was 8.3 pCi/day and 3.3 pCi/day in San Francisco. These intakes represent a slight decrease over the previous year for New York (13 percent) and a slight increase (12 percent) for San Francisco *(4.3)*.

Table 4-2 shows ^{90}Sr concentrations found in the diet for some 19 food products in San Francisco and New York City. Figure 4-2 shows the trend in ^{90}Sr concentration in these cities since 1960. The rapid decline in ^{90}Sr intakes after 1963-1964 became more gradual after 1966-67 as the uptake from the little changing cumulative deposit of ^{90}Sr on soil became the dominant factor contributing to ^{90}Sr concentrations in food.

Table 4-3 shows contributions of major food categories to average ^{90}Sr intakes since 1960 at New York City and San Francisco. Of interest is the fact that the contributions of vegetables and fruits to daily intakes have increased during recent years and in 1975 contributed more to intake than dairy products *(4.3)*.

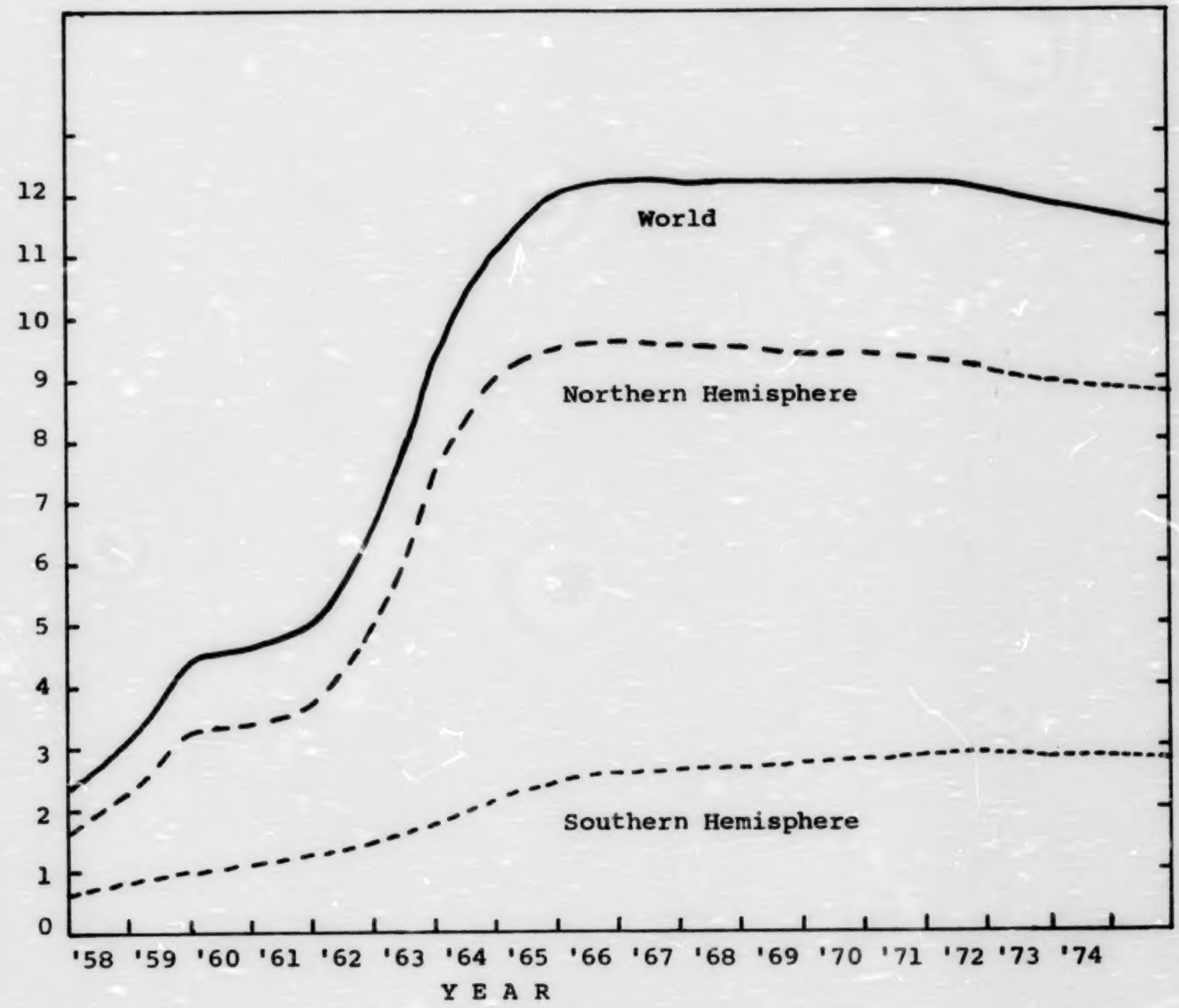

Figure 4-1. Cumulative ^{90}Sr deposition *(4.1, 4.2)*

Table 4-1. Annual cumulative worldwide ^{90}Sr deposition *(4.1)*

Year	Annual deposition (MCi)			Cumulative deposit (MCi)		
	Northern Hemisphere	Southern Hemisphere	Total	Northern Hemisphere	Southern Hemisphere	Total
Pre-1958				1.7	.6	2.3
1958	.630	.255	.885	2.28	.84	3.12
1959	1.052	.185	1.237	3.26	1.00	4.26
1960	.262	.168	.430	3.44	1.14	4.58
1961	.351	.174	.525	3.70	1.29	4.99
1962	1.444	.264	1.708	5.04	1.51	6.55
1963	2.622	.308	2.930	7.51	1.78	9.29
1964	1.656	.422	2.078	8.96	2.16	11.12
1965	.774	.357	1.131	9.50	2.46	11.96
1966	.328	.207	.535	9.59	2.60	12.19
1967	.169	.110	.279	9.52	2.65	12.17
1968	.195	.102	.297	9.48	2.68	12.16
1969	.147	.141	.288	9.40	2.76	12.16
1970	.206	.128	.344	9.37	2.82	12.19
1971	.188	.150	.338	9.33	2.90	12.23
1972	.086	.096	.182	9.18	2.92	12.10
1973	.032	.031	.063	8.99	2.88	11.87
1974	.121	.039	.160	8.89	2.85	11.74
1975	.058	.034	.092	8.73	2.81	11.54

Table 4-2. Strontium-90 in the diet during 1975 (4.2)

				New York City			San Francisco		
Diet category	kg/y	g Ca / y	% of yearly intake of Ca	pCi ^{90}Sr / kg	pCi ^{90}Sr / y	% of yearly intake of ^{90}Sr	pCi ^{90}Sr / kg	pCi ^{90}Sr / y	% of yearly intake of ^{90}Sr
Dairy products	200	216.0		5.6	1119		1.9	375	
			58			37			31
Fresh vegetables	48	18.7		10.1	487		2.0	94	
Canned vegetables	22	4.4		10.5	231		2.6	56	
Root vegetables	10	3.8		5.6	56		3.1	31	
Potatoes	38	3.8		4.9	188		2.0	78	
Dry beans	3	2.1		25.6	77		13.0	39	
			9			34			25
Fresh fruit	59	9.4		4.3	252		2.2	130	
Canned fruit	11	0.6		1.2	13		0.9	9	
Fruit juices	28	2.5		3.0	84		2.0	57	
			3			12			17
Bakery products	44	53.7		3.3	145		2.5	110	
Flour	34	6.5		5.2	176		2.2	75	
Whole grain products	11	10.3		6.7	74		5.8	64	
Macaroni	3	0.6		2.8	8		2.5	7	
Rice	3	1.1		1.4	4		1.4	4	
			20			14			22
Meat	79	12.6		0.6	50		0.4	35	
Poultry	20	6.0		1.0	20		0.4	7	
Eggs	15	8.7		1.6	24		1.1	17	
Fresh fish	8	7.6		0.2	2		0.2	1	
Shellfish	1	1.6		1.5	1		0.4	-	
			10			3			5
Yearly intake		370.0 g			3010 pCi				1190 pCi
Daily intake					8.1 pCi/g Ca 8.2 pCi/d				3.2 pCi/g Ca 3.3 pCi/d

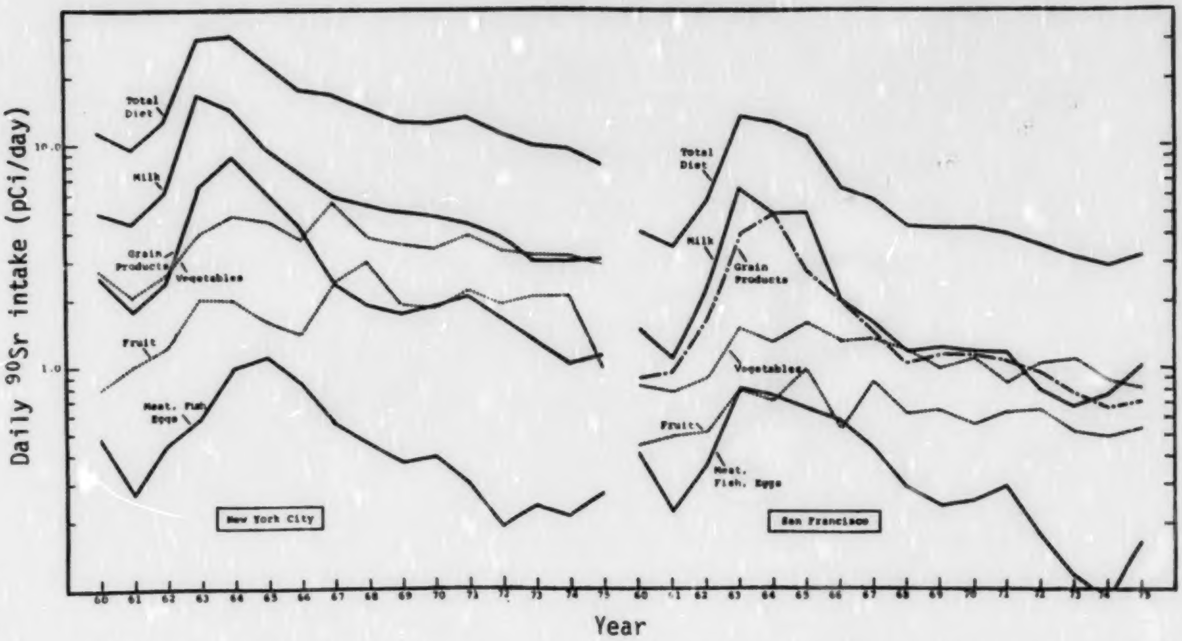

Figure 4-2. Strontium-90 intake in New York City and San Francisco *(4.3)*

Resumption of atmospheric testing by the French and Chinese in 1966, resulting in a relatively constant low fallout rate of ^{90}Sr, has been a factor in maintaining the dietary intakes of ^{90}Sr at about constant levels since 1968.

Strontium-90 in human bone

Since 1961 HASL has analyzed human vertebrae specimens obtained in New York City and San Francisco and has reported the ^{90}Sr concentrations determined from their analysis.

During 1975, 169 specimens of human vertebrae were analyzed. These specimens consisted of 32 from children and 42 from adults from New York City and 45 from children and 50 from adults obtained from San Francisco *(4.4)*.

Figure 4-3 shows ^{90}Sr in adult vertebrae for New York City and San Francisco since 1961. The data prior to 1961 in figure 4-3 are appropriate values for the earliest years of contamination in New York and was obtained from the data of Kulp and Schubert. The solid lines in figure 4-3 indicate predictions of ^{90}Sr levels made by HASL using modeling techniques. The data and lines passing through them represent measured values and standard deviations respectively.

Table 4-3. Contributions of major food categories to average daily ^{90}Sr intake *(4.2)*

	% Contribution					
	Dairy products	Grain products	Vegetables	Fruit	Meat fish, eggs	Daily intake $\frac{\text{pCi } ^{90}\text{Sr}}{\text{day}}$
New York City						
1960	43	22	24	7	4	11.3
61	47	19	22	11	3	9.6
62	48	19	20	10	4	12.7
1963	56	22	13	7	2	29.6
64	46	28	16	7	3	30.3
65	42	27	20	7	5	22.9
1966	42	24	21	8	5	17.5
67	35	14	33	14	3	16.4
68	37	13	26	20	3	14.3
1969	40	14	28	15	3	12.4
70	39	15	27	15	3	12.1
71	35	16	30	17	2	12.8
1972	35	15	30	18	2	10.7
73	31	14	32	21	2	9.7
74	32	11	33	22	2	9.5
75	37	14	34	12	3	8.3
San Francisco						
1960	36	22	21	11	10	4.0
61	31	27	22	14	6	3.5
62	40	29	16	9	6	5.5
1963	47	30	11	6	6	13.3
64	39	39	10	6	6	12.5
65	46	25	15	9	6	10.8
1966	31	31	20	8	9	6.4
67	28	26	23	15	8	5.7
68	27	24	28	15	7	4.3
1969	29	27	23	15	6	4.2
70	28	27	26	13	6	4.2
71	29	27	21	16	7	4.0
1972	22	27	29	18	5	3.6
73	21	24	35	16	4	3.2
74	26	23	30	17	3	2.9
75	31	22	25	17	5	3.3

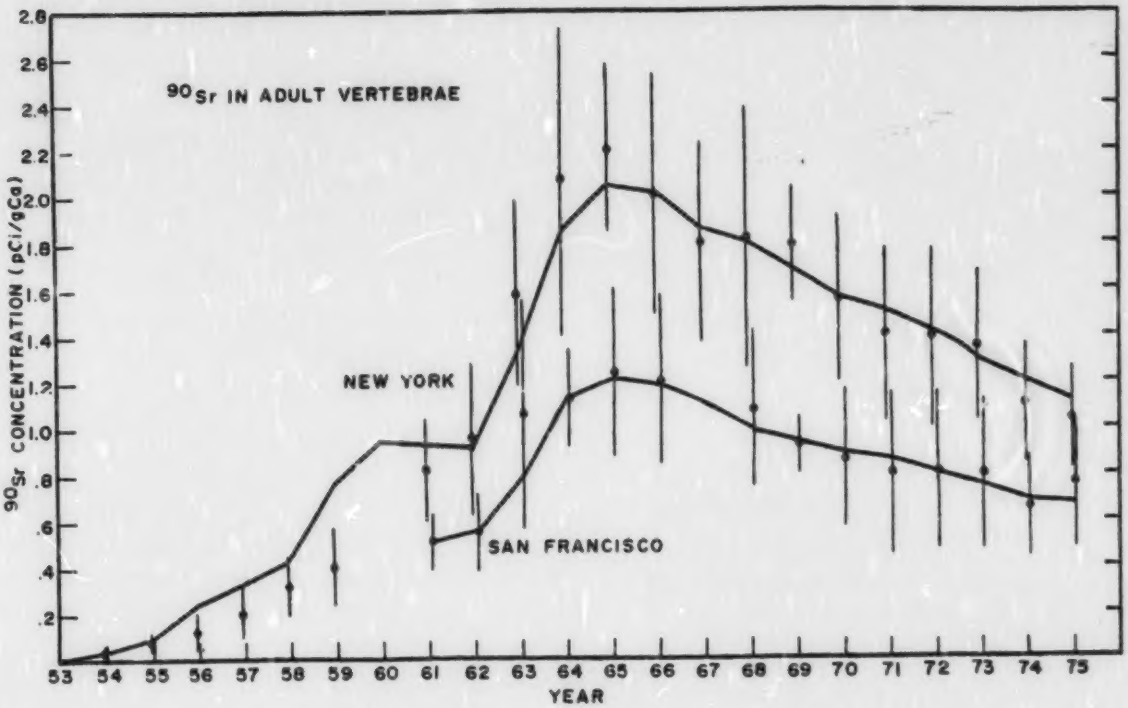

Figure 4-3. Strontium-90 in adult vertebrae - observations (points with standard deviations) and bone model predictions (solid lines) *(4.4)*

As can be seen from figure 4-3, there is a definite decreasing trend in ^{90}Sr since 1965. This decrease has been attributed by HASL to be the result of corresponding decreases in dietary ^{90}Sr intake in these cities. The large standard deviations about the average values make it difficult to accurately determine actual decreases in ^{90}Sr levels and effective removal rates *(4.4)*.

Fallout ^{239}Pu dose to man

Based upon air concentrations (measured and inferred) of ^{239}Pu in New York City, inhalation intake by man, and the ICRP Task Group lung model, Bennet *(4.5)* has estimated ^{239}Pu dose to man through the year 1972. It was assumed in performing model calculations that fallout ^{239}Pu was attached to 0.4 μm aerosol particles and that the inhalation rate was 20 m^3/d or 7300 m^3/y. Table 4-4 shows the yearly computed burdens in man for the period 1954-1972. Figure 4-4 shows the yearly ^{239}Pu intake and the cumulative burdens from 1954 through 1985. The cumulative intake through 1972 was 42.1 pCi.

Table 4-4. Fallout ^{239}Pu data - New York *(4.4)*

Year	Deposition (mCi/km^2)	Cumulative deposit (mCi/km^2)	Surface air (fCi/m^3)	Inhalation intake (pCi)	Computed burden in man (pCi)				
					Lung	Lymph	Liver	Bone	Total body
1954	.07	.07	.14	1.03	.15	.01	.00	.00	.17
1955	.09	.16	.18	1.34	.29	.03	.01	.01	.35
1956	.12	.28	.23	1.66	.43	.07	.02	.02	.54
1957	.12	.40	.23	1.66	.51	.11	.04	.04	.70
1958	.16	.56	.32	2.31	.66	.16	.07	.07	.95
1959	.23	.78	.45	3.25	.89	.21	.10	.10	1.31
1960	.04	.82	.081	.59	.63	.26	.14	.14	1.16
1961	.06	.89	.13	.91	.52	.27	.17	.18	1.14
1962	.32	1.21	.63	4.61	1.01	.31	.21	.22	1.75
1963	.62	1.83	1.68	12.23	2.46	.46	.29	.30	3.50
1964	.41	2.24	.91	6.65	2.48	.65	.39	.40	3.93
1965	.14	2.38	.33	2.39	1.86	.78	.49	.51	3.63
1966	.05	2.43	.12	.90	1.25	.81	.58	.61	3.25
1967	.04	2.47	.051	.37	.81	.78	.66	.69	2.95
1968	.04	2.51	.080	.58	.58	.72	.73	.77	2.79
1969	.06	2.57	.063	.46	.42	.65	.78	.83	2.68
1970	.03	2.60	.065	.47	.32	.59	.83	.88	2.62
1971	.03	2.63	.060	.44	.26	.54	.86	.92	2.58
1972	.02	2.65	.031	.22	.19	.48	.89	.95	2.51

The doses due to the cumulative intake of 42.1 pCi through 1972 were computed to be 15, 500, 4, and 7 mrem for the lung, lymph, liver, and bone, respectively. If one assumes that the average air concentration will be 0.01 fCi/m^3 in 1973 and that no further intake occurs beyond 1973, the cumulative doses through the year 2000 are 16, 950, 17, and 34 mrem for the lung, lymph, liver, and bone, respectively.

Comparison of the computed organ burdens against results of analyses of autopsy tissue by HASL shows that reasonable estimates of organ burdens from ^{239}Pu inhalation can be obtained from air concentrations and the ICRP Task Group model.

Fallout ^{239,240}Pu in the diet

Although inhalation of ^{239}Pu adequately accounts for organ burden, HASL has investigated *(4.6)* the occurrence of plutonium in the diet because of the long half-life involved and the resistance of plutonium in the environment.

Foods purchased in New York in 1974 for the ^{90}Sr in diet program were analyzed for ^{239,240}Pu content. The results of the analyses are shown in table 4-5. Table 4-6 shows dietary intake estimates of plutonium-239 and -240. The estimates are based upon consumption statis-

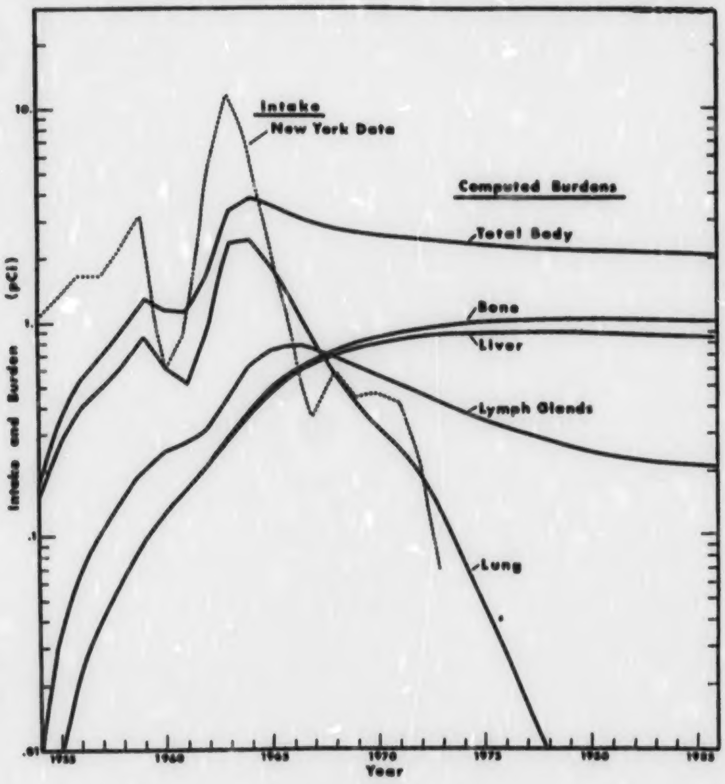

Figure 4-4. Inhalation intake and burden in man of fallout ^{239}Pu *(4.5)*

Table 4-5. Fallout $^{239,240}Pu$ in food, New York - 1974 *(4.5)*

	Sample		Concentration	
	Weight (kg)	ash (g)	dpm/sample	pCi/kg (fresh weight)
Shellfish	4.9	120	.44 ± .06	.040
Bakery products	5.6	120	.05 ± .02	.0040
Whole grain products	5.4	120	.06 ± .04	.0050
Fresh fruit	17.9	120	.10 ± .04	.0025
Dry beans	3.2	120	.03 ± .02	.0043
Fresh vegetables	16.2	120	.11 ± .02	.0031
Root vegetables	18.6	120	.08 ± .02	.0019
Poultry	16.9	120	.21 ± .04	.0056
Flour	24.2	120	.05 ± .02	.00093
Meat	14.4	120	.08 ± .03	.0025
Fresh fish	10.5	120	.04 ± .02	.0017
Rice	11.5	70	≤.02	<.00078
Potatoes (peeled)	11.2	120	.03 ± .02	.0012
Eggs	12.9	120	.06 ± .03	.0021
Macaroni	19.0	120	.04 ± .02	.00095
Canned vegetables	10.9	120	≤.02	<.00083
Milk	33.4	240	.11 ± .04	.0015
Fruit juices	19.5	120	.03 ± .02	.00069
Canned fruit	46.6	120	.04 ± .02	.00039
Tap water	1200	-	.80 ± .08	.00030

Table 4-6. Fallout ^{239,240}Pu dietary intake, New York-1974 *(4.5)*

Item	Consumption (kg/y)	Concentration (pCi/kg)	Intake (pCi/y)
Bakery products	44	.0040	.18
Fresh fruit	59	.0025	.15
Fresh vegetables	48	.0031	.15
Meat	79	.0025	.20
Flour	34	.00093	.032
Whole grain products	11	.0050	.055
Poultry	20	.0056	.11
Milk	200	.0015	.30
Potatoes	38	.0012	.046
Root vegetables	10	.0019	.019
Canned vegetables	22	.00083	<.018
Eggs	15	.0021	.031
Dry beans	3	.0043	.013
Fresh fish	8	.0017	.014
Shell fish	1	.040	.040
Fruit juice	28	.00069	.019
Rice	3	<.00078	<.0023
Macaroni	3	.00095	.0028
Canned fruit	11	.00039	.0042
Tap water	1200	.0003	.15
		TOTAL	1.5 pCi/y

tics and concentration data. The estimated dietary intake of fallout $^{239,240}Pu$ during 1974 was estimated to be 1.5 ± 0.5 pCi by HASL. The contribution to this intake was about 26 percent from meat, poultry, eggs and fish, 20 percent from dairy products, 18 percent from grain products, 15 percent from vegetables, 11 percent from fruit and 10 percent from tap water.

Changes in plutonium concentration in foods from 1972 to 1974 are shown in figure 4-5. The standard deviations based upon counting statistics are represented by the vertical bars in the figure. Within these uncertainties in concentration, there have been few changes since 1972.

HASL has estimated dietary intake from $^{239,240}Pu$ during 1972-1974 to be 1.6 ± 0.3 pCi/y. Contributions to this estimate by various food products are shown in table 4-7.

In addition to dietary samples, HASL has collected and analyzed weekly samples of tap water. The results of this analysis since 1973 is shown in figure 4-6. The annual means for these years are 0.22 + 0.04 fCi/liter, 0.30 ± 0.03 fCi/liter, and 0.25 ± 0.02 fCi/liter for 1973, 1974, and 1975, respectively. The mean for the entire period was 0.25 ± 0.02 fCi/liter.

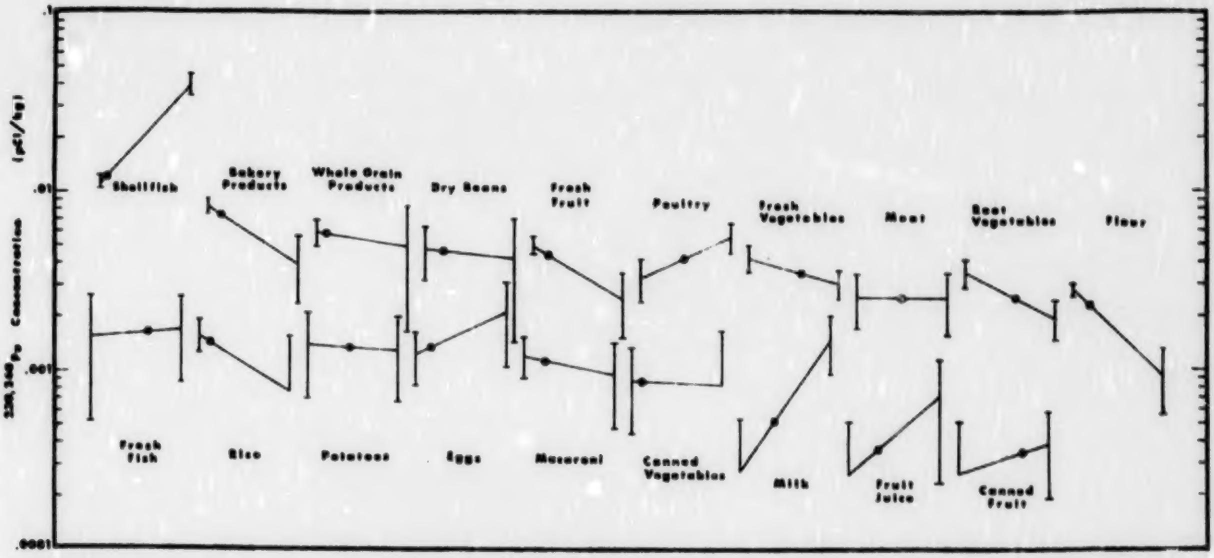

Figure 4-5. Changes in $^{239,240}Pu$ concentrations in foods from 1972 (left) to 1974 (right). The means of each pair of determinations (points) are weighted according to indicated counting uncertainties. Values below the minimum detection level (±100% uncertainty) have no downside uncertainty indicated *(4.6)*

Table 4-7. Fallout $^{239,240}Pu$ dietary intake, New York, 1972-74 *(4.5)*

Item	Consumption (kg/y)	Mean concentration (pCi/kg)	Intake (pCi/y)
Shellfish	1	.012 ± .0009	.012
Bakery products	44	.0075 ± .0007	.33
Whole grain products	11	.0059 ± .0010	.065
Dry beans	3	.0047 ± .0014	.014
Fresh fruit	59	.0045 ± .0005	.26
Poultry	20	.0043 ± .0007	.085
Fresh vegetables	48	.0035 ± .0004	.17
Meat	79	.0025 ± .0006	.20
Root vegetables	10	.0025 ± .0004	.025
Flour	34	.0023 ± .0002	.079
Fresh fish	8	.0017 ± .0007	.013
Rice	3	.0015 ± .0003	.0044
Potatoes	38	.0014 ± .0005	.052
Eggs	15	.0014 ± .0004	.020
Macaroni	3	.0011 ± .0003	.0034
Canned vegetables	22	.00087 ± .00039	.019
Milk	200	.00051 ± .00024	.10
Fruit juice	28	.00036 ± .00022	.010
Canned fruit	11	.00035 ± .00016	.0038
Tap water	511	.00026 ± .00002	.14
		TOTAL	1.6 ± .3 pCi/y

Based upon their program and using an estimate that the uptake from the gastrointestinal tract ranged from 3 x 10^{-5} to 10^{-6} pCi/y, HASL estimates that the 1.6 pCi/y intake during 1972-1974 contributed, at most, 5 x 10^{-5} pCi/y to the body burden. During the same period, inhalation intake averaged 0.2 pCi/y of which about 4 x 10^{-2} pCi/y contributed to the initial lung and body burden. Thus, at present, deposition and air activity of fallout plutonium, this inhalation pathway contribution to body burden is about a factor of 1000 higher then the ingestion pathway.

United Nations Scientific Committee on the Effects of Atomic Radiation

Perhaps the best source of dose information derived from many different sources of fallout data, including the HASL data, has been provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The sixth substantive report of UNSCEAR reviews radiation received from all sources to which man is exposed.

Fallout dose information presented by UNSCEAR in the 6th report is currently being updated and should be published in 1977. Although the most recent published report doses not contain dose data up to and including the year 1975, it does contain in one single reference the most complete and recent dose information available with some few exceptions such as the HASL plutonium doses discussed previously. Presented below is the dose information contained in the latest UNSCEAR report.

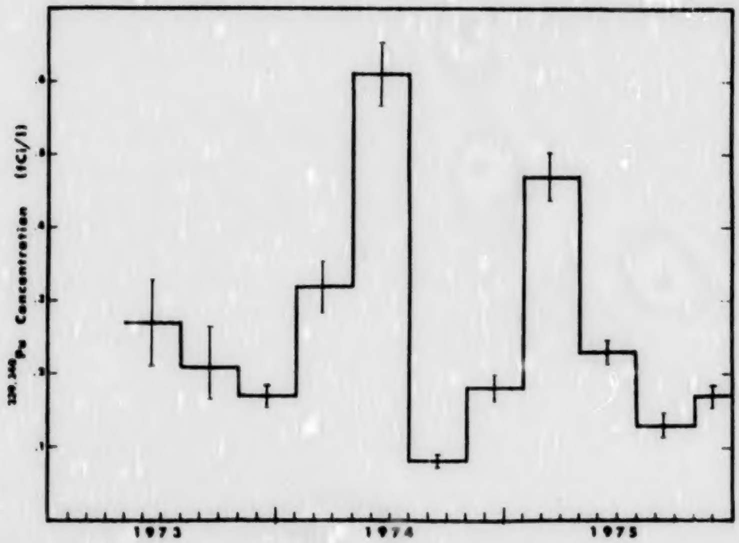

Figure 4-6. ^{239,240}Pu in tap water in New York *(4.6)*.

Tritium doses

Based upon an estimated 1900 megacuries of tritium released by nuclear weapons tests up to 1963 *(4.6)* (most of which was in the Northern Hemisphere), the UNSCEAR estimates the dose commitments to be 4 and 1 millirads for the Northern and Southern Hemispheres, respectively *(4.6)*.

Carbon-14

The total estimated ^{14}C inventory from weapons tests has been estimated to be 6.2 megacuries compared to a natural inventory of 280 megacuries. UNSCEAR estimates dose commitments of 140 millirads and 170 millirads to soft tissue and endosteal cells, respectively. Because of the long halflife of ^{14}C, most of the dose commitment occurs over thousands of years; the part of the commitment that will occur up to the year 2000 is estimated to be 12 millirads to the gonads and 14 millirads to the cells lining bone surfaces *(4.7)*.

Iron-55

The total production of ^{55}Fe from tests since 1961-1962 is estimated to be about 50 megacuries. Activity estimates based upon monitoring in North and South America dropped from about 500 fCi/m^3 to a few femtocuries per cubic meter by 1970. Body burdens calculated from different places about the world range from 20-30 nanocuries in 1966 to 1-10 nanocuries in 1969. Assuming a maximum body burden of about 30 nanocuries in the temperate latitudes, dose estimates are 1 millirad to the gonads and bone-lining cells and 0.6 millirads to the bone marrow. For the Southern Hemisphere, doses are estimated to be about 1/4 that of the temperate latitudes *(4.7)*.

Krypton-85

The atmospheric inventory of ^{85}Kr produced by nuclear weapons tests has been estimated to be about 3 megacuries. ^{85}Kr is a beta emitter, however, it also produces a gamma photon in 0.4 percent of the disintegrations. By external irradiation, beta rays deliver a dose to the skin and to subcutaneous tissues, while gamma radiation is responsible for whole body and gonad doses. Internal radiation also occurs from inhalation. The dose to the gonads from external radiation is estimated to be 17 nrad/y per pCi/m^3. The dose commitment to the gonads is estimated to be about 0.2 microrad *(4.7)*.

Radiostrontium

Based upon ^{90}Sr deposition measurements taken worldwide and calculations of uptake by man in diet, the UNSCEAR has estimated the dose commitment from ^{90}Sr from all tests up to 1970 (table 4-8) *(4.7)*.

Table 4-8. Estimated dose commitment from strontium-90

Organ	Northern Hemisphere		Southern Hemisphere	
	Temperate latitudes (mrad)	Average (mrad)	Temperate latitudes (mrad)	Average (mrad)
Bone marrow	62	45	17	11
Endosteal cells	85	61	23	15

Iodine-131

Iodine-131 fallout deposition patterns are unpredictable throughout the world; hence, the estimation of worldwide doses is not possible unless extensive data on deposition and milk production and consumption throughout the world are known. Because of the limitation of data, UNSCEAR has only provided estimates of ^{131}I doses at some local areas throughout the world, but did not include the United States.

Cesium-137

UNSCEAR estimates that the average integrated deposits of ^{137}Cs in the northern and southern temperate latitudes are 128 and 35 nCi/m^2, respectively. The corresponding dose commitments from diet for these deposits are 26 and 7 millirads. If the dose commitments are calculated on a population-weighted basis over the whole of each hemisphere, the commitments are 19 and 4 millirads for the Northern and Southern Hemispheres, respectively *(4.7)*.

External dose commitments from ^{137}Cs ground deposition have been estimated for the period 1950-1970 to be 134 and 32 millirads for the Northern and Southern Hemispheres, respectively *(4.7)*.

Plutonium

Based upon estimates of the total integrated level of fallout plutonium since the beginning of weapons tests to 1970, the UNSCEAR estimates that the integrated doses over 50 years to be 2, 400, 0.8, and 0.2 millirads to the pulmonary region, the lymph nodes, the liver, and the bone, respectively *(4.7)*.

Short-lived fission products

UNSCEAR, using ^{90}Sr deposition data up to 1967 at Abingdon, United Kingdom, has computed an estimate of the Northern Hemisphere, population-weighted, dose commitment of 144 millirads. Based upon estimates of fallout of ^{90}Sr for 1968-1969, a dose commitment of 4 millirads for 1968-1969 is estimated. Thus, the total population-weighted dose commitment for short-lived fission products for 1961-1969 is estimated as 148 millirads for all deposition in the Northern Hemisphere, and the dose commitment for the northern temperate latitudes is estimated as 203 millirads *(4.7)*.

Based upon ^{90}Sr deposition from 1961-1969 in the Southern Hemisphere to the dose commitment from short-lived products is estimated by UNSCEAR to be 40 millirads. In the southern temperate regions, it is estimated to be 60 millirads *(4.7)*.

Summary - UNSCEAR results

Table 4-9 summarizes UNSCEAR estimates of dose commitments from weapons tests conducted prior to 1971. Table 4-9 also presents estimates given in the UNSCEAR 1969 report for tests conducted prior to 1968. Although no major series of tests were conducted during the period 1968-1970, there are significant differences between the estimates made for internal dose commitments from ^{90}Sr to bone-lining cells and for external dose commitments to all tissues. These changes are mostly due to the availability of improved information *(4.7)*. As a result, the ratios of external to internal estimated dose commitments for all tissues are higher for 1972 than 1969.

Because of the higher dose commitments for external radiation and lower dose commitments from ^{90}Sr, the relative importance of ^{90}Sr has decreased and ^{137}Cs appears to be the main contributor to total dose commitment *(4.7)*.

Predicted doses

A prediction of doses from atmospheric nuclear tests was made in a study published in 1972 *(4.8)*. A summary of these doses is presented in table 4-10.

Summary

UNSCEAR provides population-weighted dose estimates on a worldwide basis usually reported by temperate zone in each hemisphere. The disadvantage to this reporting procedure is that this information is not specific to the United States. However, in a way, the data indicate that the annual cumulative worldwide deposition reached a maximum around

Table 4-9. Dose commitments from nuclear tests carried out before 1971. (The dose commitments from nuclear tests carried out before 1968, taken from the 1969 report, are indicated between parentheses) *(4.7)*

	Dose commitments (mrad) for the north temperate zone			Dose commitments (mrad) for the south temperate zone			Dose commitments (mrad) to the world population		
Source of radiation	Gonads	Bone-lining cells	Bone marrow	Gonads	Bone-lining cells	Bone marrow	Gonads	Bone-lining cells	Bone marrow
External									
Short-lived	65 (36)	65 (36)	65 (36)	19 (8)	19 (8)	19 (8)	44	44	44
^{137}Cs	59 (36)	59 (36)	59 (36)	16 (8)	16 (8)	16 (8)	40	40	40
^{85}Kr	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Internal									
^{3}H	4	4	4	1	1	1	4	4	4
^{14}C	12 (13)	15 (16)	12 (13)	12 (13)	15 (16)	12 (13)	12	15	12
^{55}Fe	1	1	0.6	0.3	0.3	0.2	0.7	0.7	0.4
^{90}Sr		85 (130)	62 (64)		23 (28)	17 (14)		57	42
^{137}Cs	26 (21)	26 (21)	26 (21)	7 (4)	7 (4)	7 (4)	18	18	18
^{239}Pu[(a)]		0.2			0.05			0.1	
Total[(b)]	170 (110)	260 (240)	230 (170)	55 (33)	81 (64)	72 (47)	120	180	160

[(a)] The dose commitment to bone-lining cells for the north temperate zone has been taken to be equal to the integrated dose over 50 years to bone. A reduction by a factor of four has been assumed for the south temperate zone. Because of insufficient data, the dose commitments to gonads and to bone marrow have not been estimated.

[(b)] Totals have been rounded off to two significant figures.

1965, and it has been decreasing ever since as radioactive decay exceeds fallout. Table 4-9 of this chapter summarizes the estimates of dose commitment from the significant fission products of fallout resulting from tests conducted prior to 1971. Although the data are reported on a global basis, they indicate that most of the dose is committed to the population in the Northern Hemisphere and that ^{137}Cs appears to be the most significant contributor to this dose commitment. An estimation of the doses to the U.S. population from fallout was presented in table 4-10. These estimations indicate that the per capita dose will increase slightly during the 1970 to 2000 time period.

Table 4-10. Total annual whole-body doses from global fallout *(4.8)*

Year	U.S. population (millions)	Per capita dose (mrem)	Dose for U.S. population (10^6 person-rem)
1963	190	13	2.4
1965	194	6.9	1.3
1969	204	4.0	0.82
1980	237	4.4	1.1
1990	277	4.6	1.3
2000	321	4.9	1.6

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(4.5) BENNETT, B. G. Fallout ^{239}Pu dose to man. U.S. Atomic Energy Commission Report HASL-278, pp. I-41 to I-63 (January 1, 1974).

(4.6) BENNETT, B. G. Fallout ^{239,240}Pu in the diet: 1974 results. U.S. Energy Research and Development Administration Report, HASL-306, pp. I-115 to I-131 (July 1, 1976).

(4.7) UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. Ionizing Radiation Levels and Effects Volume 1: Levels, United Nations, New York (1972).

(4.8) KLEMENT, A. W. JR., C. P. MILLER, R. P. MINX, AND B. SHLEIEN. Estimates of ionizing radiation doses in the United States: 1960-2000, ORP/CSD 72-1. U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C. (August 1972).

Chapter 5 - Uranium Fuel Cycle

Uranium Mining and Milling

Uranium has been milled in the United States since the late 1940's. Ores containing uranium have actually been mined since around 1900 in the Slickrock, Colo., area where the ore was delivered by mules to the railroad and shipped to a radium mill in Pennsylvania *(5.1)*.

Mining locations in the United States

Uranium ore-producing mines have been operated in the States of Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. From 1948 to 1975, 282,400 tons of U_3O_8 have been produced from 124,327,000 tons of ore in the United States (average 0.23 percent U_3O_8). Most of the ore (75 percent) presently comes from the States of New Mexico and Wyoming, 45 and 30 percent (1975), respectively *(5.2)*. The significant uranium areas of the United States are listed in table 5-1. The Colorado plateau area shown in figure 5-1, accounting for 66 percent of the U_3O_8 (produced and known $10 reserves), includes the four corners area of Arizona, Colorado, New Mexico, and Utah. The Wyoming Basins account for 23 percent, and all others, 11 percent of these reserves.

Most of the $15 and $30 uranium reserves are also found in the Colorado Plateau and Wyoming Basins ($15-52 percent and 36 percent; $30-51 percent and 36 percent, respectively). Based upon present production, the States of New Mexico and Wyoming contain most of the $15 and $30 reserves (New Mexico, 48 percent and 47 percent, respectively; and Wyoming, 37 percent and 37 percent, respectively.

The number of acres held by the uranium industry for exploration and mining peaked in 1969 and on January 1, 1970, 27,279,000 acres were held. The acreage held then decreased through 1972; and on January 1, 1973, 17,677,000 acres were involved. Since then the acres held have shown an increase each year on January 1 (1974-18.8 million; 1975-21.3 million). As of January 1, 1976, 22,911,000 acres were held. Forty-four percent of this land was in the State of Wyoming (10,090,000 acres) followed by Utah (18 percent), New Mexico (16 percent), and Colorado (7 percent). The remaining 10 States ranged from Arizona with 942,000 acres (4 percent) to Oregon with 31,000 acres (0.1 percent) *(5.2)*.

Table 5-1. Significant uranium areas of the United States *(5.2)*

State	Area	U_3O_8 production and reserves	
		> 500 tons	< 500 tons > 10 tons
Alaska	Prince of Wales Island	X	
Arizona	Cameron	X	
	Grand Canyon	X	
	Globe		X
	Monument Valley	X	
	Tuba City		X
	West Central		X
California	East Central		X
	Southeast		X
Colorado	Front Range	X	
	Gunnison		X
	Marshall Pass	X	
	Maybell	X	
	Rifle		X
	Uravan Mineral Belt	X	
Idaho	Lowman		X
Montana	South Central Border		X
Nevada	Austin		X
	North Central		X
New Mexico	Grants Mineral Belt	X	
	Laguna		X
	Shiprock	X	
North Dakota	Belfield		X
Oregon	Lakeview		X
South Dakota	Cave Hills	X	
	Edgemont	X	
	Slim Buttes	X	
Texas	Falls City	X	
	Ray Point	X	

Table 5-1. Significant uranium areas of the United States cont.

State	Area	U_3O_8 production and reserves	
		> 500 tons	< 500 tons > 10 tons
Utah	Canyon Lands		X
	Green River	X	
	Inter River (Moab)	X	
	Lisbon Valley	X	
	Marysvale	X	
	Mexican Hat		X
	San Rafael	X	
	Thompson		X
	White Canyon	X	
Washington	Spokane (Ford)	X	
	North of Spokane		X
Wyoming	Black Hills	X	
	Crooks Cap	X	
	Gas Hills	X	
	Powder River Basin	X	
	Shirley Basin	X	

The Bendix Field Engineering Corporation performs as a prime operating contractor for the ERDA's Grand Junction Operations Office and has published a report which summarizes the work done in support of ERDA's National Uranium Resource Evaluation or NURE program. During 1976, nearly 80,000 miles of aerial surveys were flown; samples were analyzed by four ERDA laboratories, 50 geologic study projects were started, remote sensing LANDSAT data were analyzed, a drilling program was initiated, and various related development programs were in progress *(5.3)*.

Aerial radiometric reconnaissance is used to determine broad source regions of uranium occurrence. This equipment is calibrated using a calibration-pad which contains known amounts of uranium, thorium, and potassium. This facility in Grand Junction, Colo., is available without charge to firms and organizations for calibration of airborne or vehicle-born spectrometer systems.

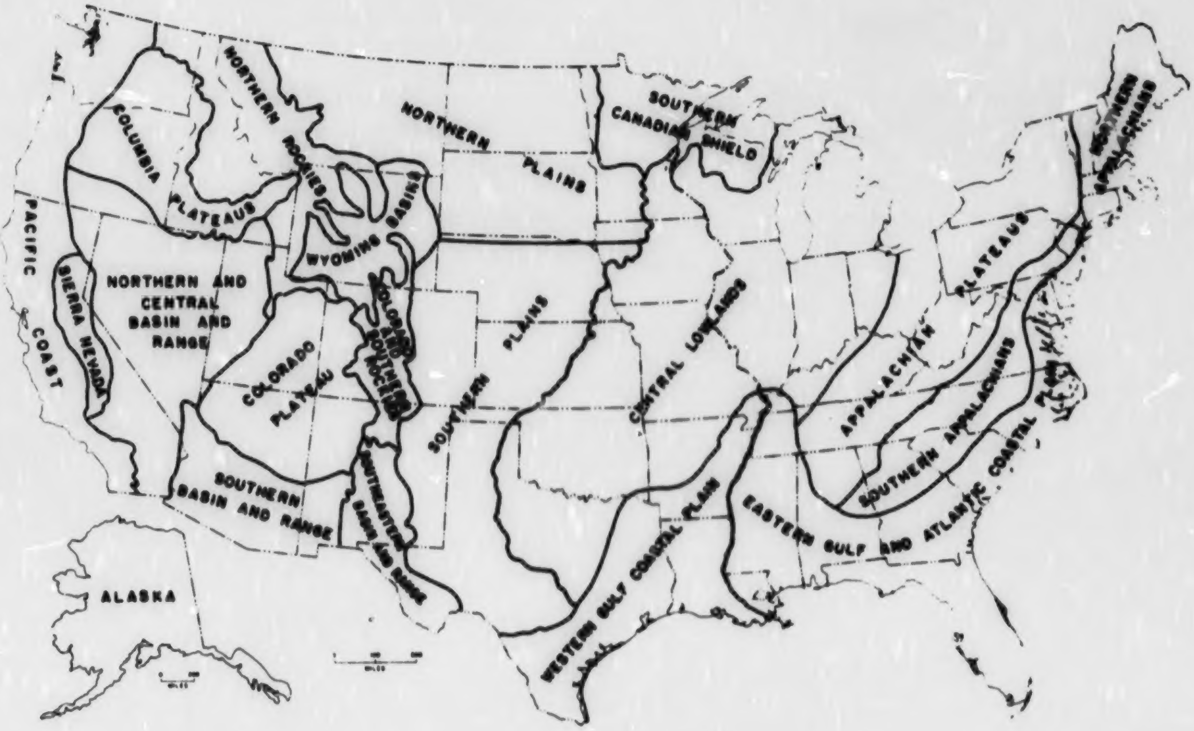
NORTHERN ROCKIES
COLUMBIA PLATEAUS
NORTHERN PLAINS
SOUTHERN CANADIAN SHIELD
NORTHERN APPALACHIANS
PACIFIC COAST
SIERRA NEVADA
NORTHERN AND CENTRAL BASIN AND RANGE
WYOMING BASINS
COLORADO AND SOUTHERN ROCKIES
COLORADO PLATEAU
SOUTHERN PLAINS
CENTRAL LOWLANDS
APPALACHIAN PLATEAUS
SOUTHERN APPALACHIANS
ATLANTIC COASTAL PLAIN
SOUTHERN BASIN AND RANGE
SOUTHEASTERN BASIN AND RANGE
EASTERN GULF AND ATLANTIC COASTAL PLAIN
WESTERN GULF COASTAL PLAIN
ALASKA

Figure 5-1. Geological resource regions of the United States *(5.2)*

The NURE program should expand the potential areas to look for uranium reserves, but it should also add much information regarding the gamma exposure from naturally occurring nuclides throughout the United States. It is also envisioned that other efforts such as the studies on emanometry techniques (measurement of radon and helium gas decay products from the uranium chain) will produce techniques and equipment that will be useful in other areas of natural radioactivity.

Types of uranium recovery

Two major types of uranium recovery are practiced in the United States, strip or pit mining and underground mining. Strip mining produces the largest amount of waste because of stripping the overburden from above the ore horizon. For instance, in Wyoming during 1974, 2,666,000 tons of uranium ore were mined. The wastes produced were 103,531,000 tons of overburden, 515,000 tons of waste rock, and 2,984,000 tons of mill tailings. Colorado mined 1,216,000 tons of ore and produced 1,210,000 tons of tailings *(5.4)*. All of Colorado's production was from underground mines, while almost all of Wyoming's production comes from strip mines; thus, strip mining produces vast quantities of waste.

Uranium (U_3O_8) is also again being recovered from waste streams of the phosphate industry. During the 1950's and early 1960's about 500 tons of U_3O_8 were recovered in conjuction with phosphoric acid production. This method of uranium recovery was resumed in 1975. The uranium recovered from the waste streams has been called by-product uranium. Extensive research and development has also been performed with copper dump leach liquor. Estimates based on production through the year 2000, indicate 140,000 tons of U_3O_8 from phosphate and 25,000 tons of U_3O_8 from copper will be available *(5.2)*.

A new category of uranium recovery called solution mining is now also being used. Mining companies for a number of years have used such techniques as heap leaching, primarily for recovering the uranium from old uranium mill tailings piles. A new technique which has been used in Texas and started in Wyoming in 1976 is called in situ mining.

This process currently consists of pumping a sulfuric acid leach solution into the uranium-bearing formation through injection wells and recovering the leach liquor through a production well. The uranium is extracted from the pregnant liquor on ion exchange columns, eluted from the columns with sulfuric acid and hydrogen peroxide, precipitated with manganese oxide, and filtered. At present, an impure yellow cake results (about 50 percent U_3O_8); thus, the product will be shipped to a conventional mill for further refining.

Active uranium mills

The uranium mills that were in operation in the United States as of January 1, 1976, are shown in figure 5-2 and listed in table 5-2. Ninety-three percent of the stated nominal daily milling capacity was centered in the States of New Mexico (48 percent), Wyoming (33 percent), Colorado (6 percent), and Utah (6 percent). The remaining 7 percent was in the States of Texas (6 percent) and Washington (1 percent). Figures 5-3 to 5-6 show the trends that have been developing in the uranium mining and milling industry since 1965.

Strip mining probably produces more problems for the environment than underground mining, but while underground mining does not produce as great a volume of waste, it produces greater hazards for the miners. Rock falls and equipment accidents are constantly present and another hazard underground is the exposure to the radon daughters produced from radon.

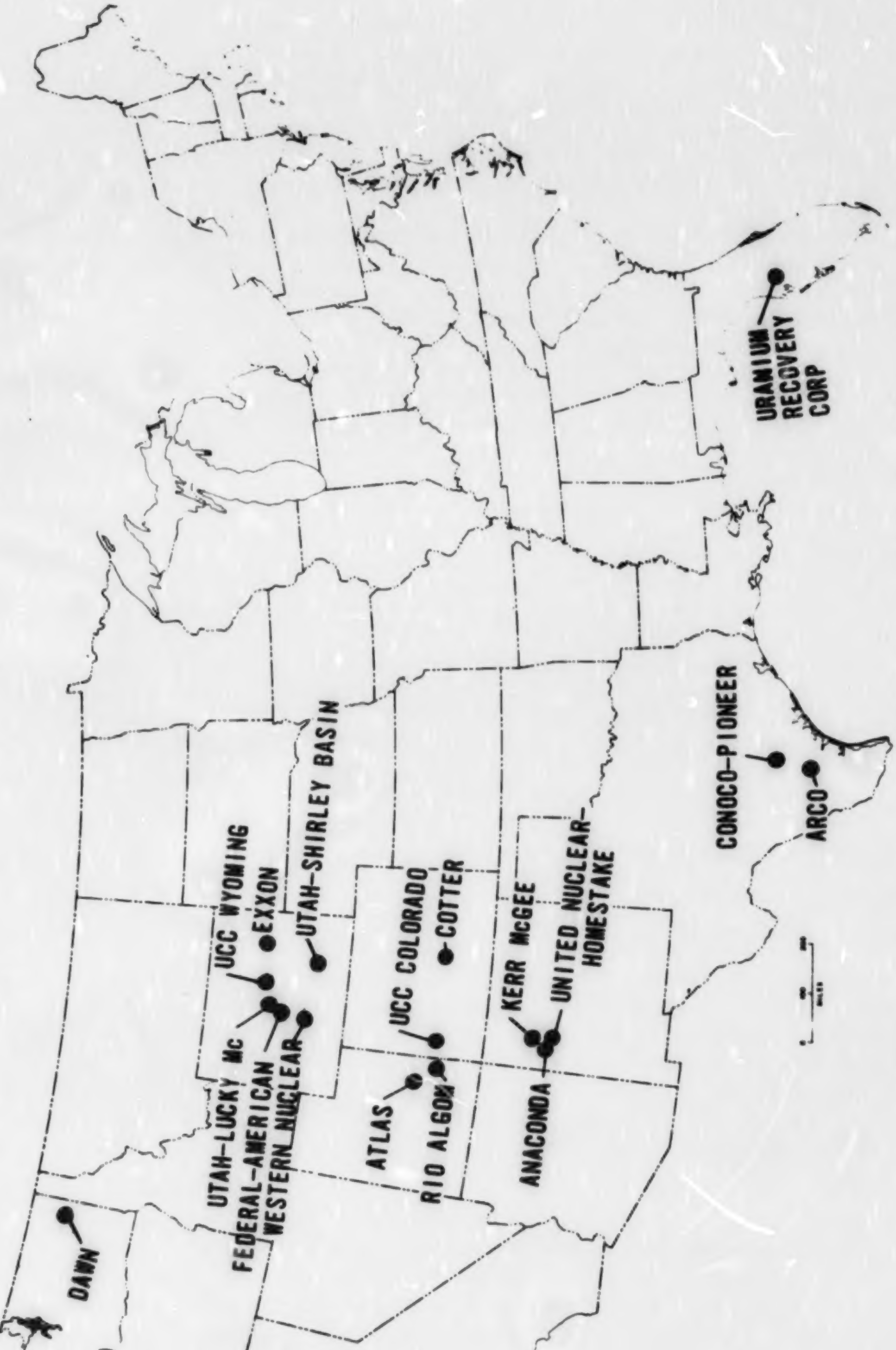
DAWN
UTAH-LUCKY MC
FEDERAL-AMERICAN
WESTERN NUCLEAR
UCC WYOMING
EXXON
UTAH-SHIRLEY BASIN
ATLAS
RIO ALGOM
UCC COLORADO
COTTER
ANACONDA
KERR McGEE
UNITED NUCLEAR-HOMESTAKE
CONOCO-PIONEER
ARCO
URANIUM RECOVERY CORP

Figure 5-2. Active uranium ore processing facilities *(5.2)*

Table 5-2. U.S. uranium mills as of January 1, 1976 *(5.2)*

Company	Location	Nominal Capacity (tons ore per day)
Anaconda Company	Grants, New Mexico	3,000
Atlantic-Richfield	George West, Texas	1/
Atlas Corporation	Moab, Utah	1,000
Conoco-Pioneer	Falls City, Texas	1,750
Cotter Corporation	Canon City, Colorado	450
Dawn Mining Company	Ford, Washington	400
Exxon Company, USA	Powder River Basin, Wyoming	3,000
Federal-American Partners	Gas Hills, Wyoming	950
Kerr-McGee Nuclear Corp.	Grants, New Mexico	7,000
Rio Algom Corporation	LaSal, Utah	700
Union Carbide Corporation	Uravan, Colorado	1,300
Union Carbide Corporation	Gas Hills, Wyoming	1,200
United Nuclear-Homestake Partners	Grants, New Mexico	3,500
Uranium Recovery Corp.	Mulberry, Florida	2/
Utah International, Inc.	Gas Hills, Wyoming	1,200
Utah International, Inc.	Shirley Basin, Wyoming	1,800
Western Nuclear, Inc.	Jeffrey City, Wyoming	1,200
Total		28,450

1/ Uranium obtained by solution mining.

2/ Uranium recovered from phosphoric acid.

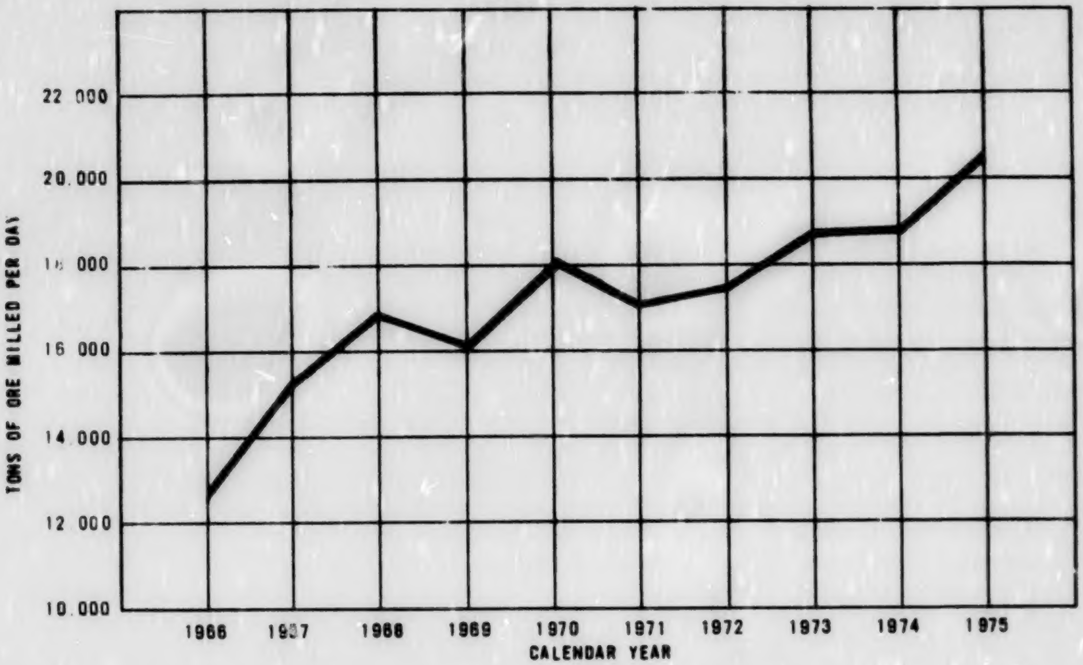

Figure 5-3. Uranium ore processing rates *(5.2)*

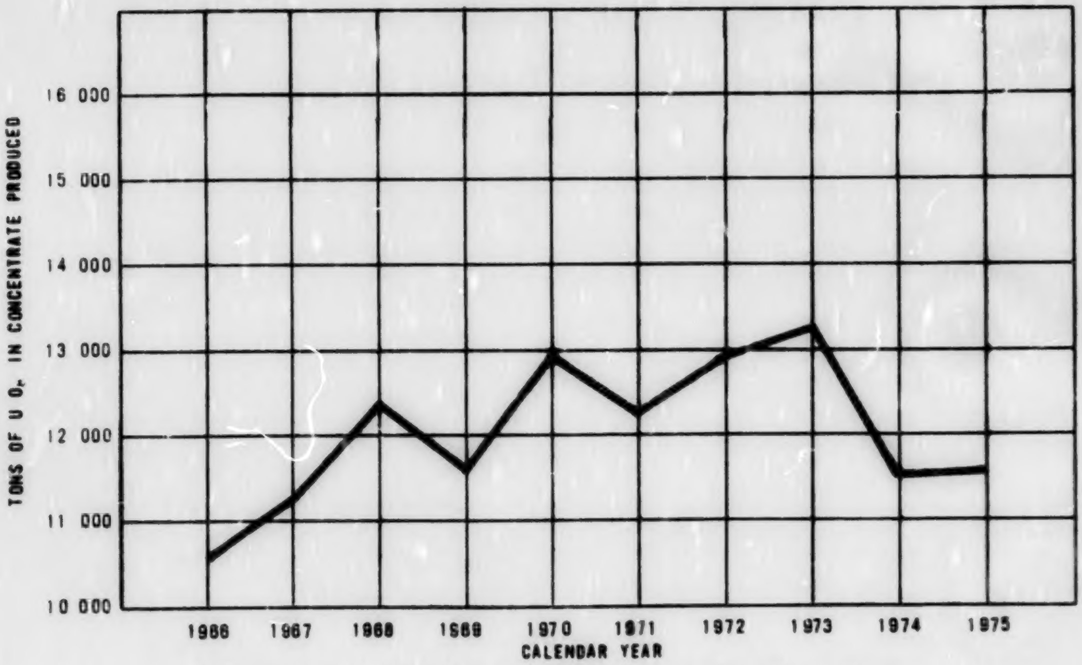

Figure 5-4. Uranium concentrate production *(5.2)*
(includes production from millfeed other than ore)

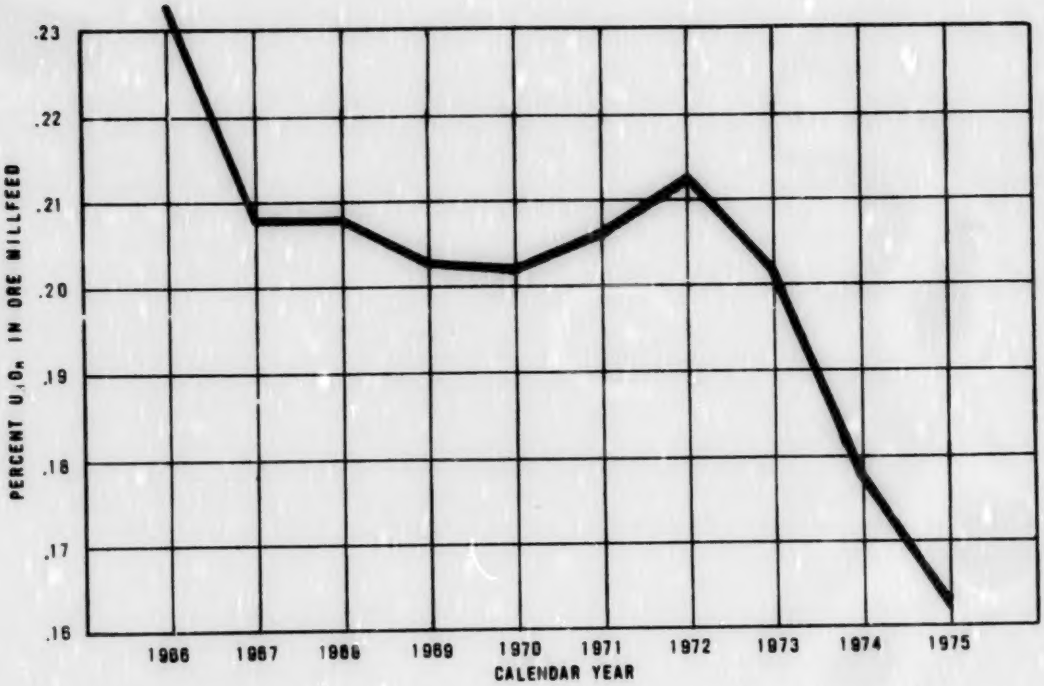

Figure 5-5. Grade of uranium ore processed *(5.2)*

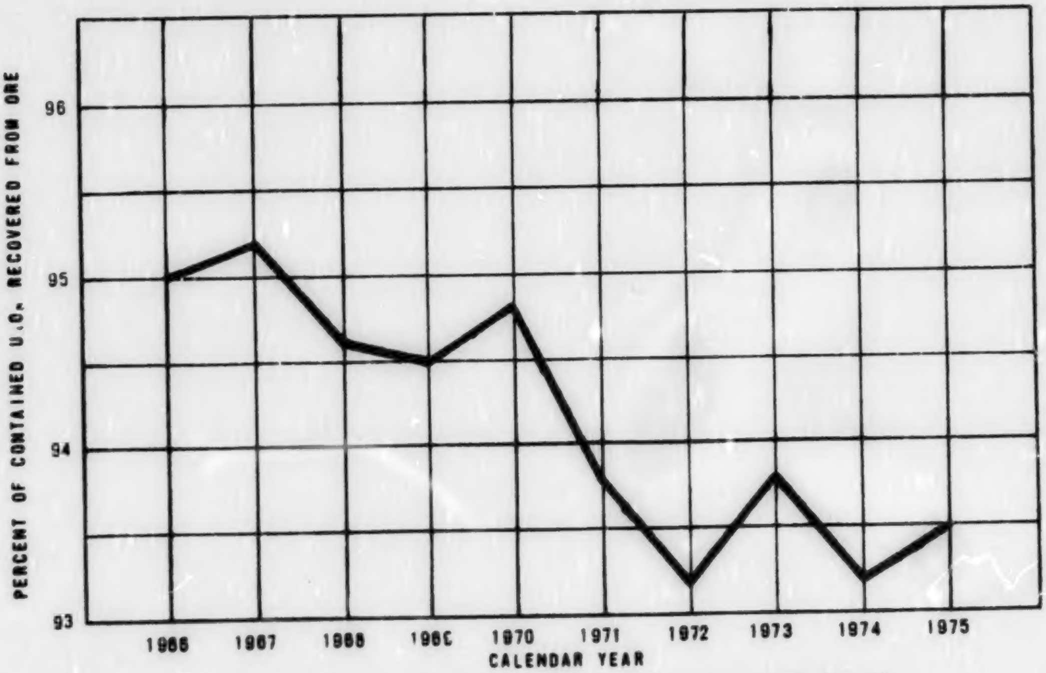

Figure 5-6. Recovery from ore processed *(5.2)*

Dose data

Although the doses to actual individuals or populations living in the vicinity of uranium mills have not been documented, doses have been predicted for a model uranium mill *(5.5)* and Ford, Bacon and Davis has prepared exposure estimates in the Phase II reports that have been released *(5.6)*. Dose estimates from routine effluents of a model mill to individuals in the vicinity of the mill through the air pathway are given in table 5-3. The estimated doses to the population in the vicinity of the mill are given in table 5-4.

Fuel Enrichment (5.7) (5.8)

Gaseous diffusion technology is used to enrich uranium-235 content from about 0.7 percent to about 4 percent for use in light-water reactors and to about 90 percent enrichment for use in high temperature gas-cooled reactors.

Radiation doses to individuals and to the population from various pathways were estimated by ERDA for annual releases of radioactive effluents from normal operation of 8.75 million SWU/y enrichment plants.

Table 5-5 shows the estimated total body dose to an individual at the facility boundary 1200 meters from the plant, resulting from all exposure pathways. Gaseous effluents contribute approximately 98 percent of the estimated dose to the total body. Dose estimates resulting from the principal radionuclides in the gaseous effluents are given in table 5-6 for a number of organs. Tables 5-7 and 5-8 are summaries of the estimated population doses over an 80-km radius from the plant. Gaseous effluents are shown to be the primary contributors to population total body dose. Contaminated ground surface and ingestion are the exposure pathways that contribute over 80 percent of the estimated population dose for all reference organs other than the lungs, for which inhalation is the most important exposure pathway.

In summary, the isotopes of interest in the enrichment plants are uranium-234, -235 and -238 and naturally occurring daughters. The environmental data indicate that it is unlikely that diffusion operations significantly increase levels of exposure to the general population.

Fuel Fabrication Plants (5.8) (5.9) (5.10)

In the final fuel fabrication step, UF_6 is hydrolyzed to uranyl fluoride, converted to ammonium diuranate and calcined to the dioxide. The dioxide powder is pelletized, sintered and loaded into stainless

Table 5-3. Radiation doses to individuals due to inhalation in the vicinity of a model mill[a] *(5.5)*

Radionuclide	Source term (mCi/y)	Critical organ	Dose equivalent to critical organ	
			Individual at plant boundary (mrem/y)	Average individual within 80 km (mrem/y)
Uranium-234 and 238	180	Lung	170	3.9×10^{-2}
Thorium-230	15	Lung	15	3.4×10^{-3}
Radium-226	10	Lung	15	2.2×10^{-3}
Total	205		200	4.5×10^{-2}

[a] Characteristics of a model mill are assumed to be:

1. 600,000 Mt ore milled per year
2. 1,140 Mt U_3O_8 as yellowcake produced per year
3. Use of acid leach process
4. A tailings retention pond system which uses a clay-core earth dam and local topographic features of the area to form impoundment
5. Collection and return of any seepage through the dam to the tailings pond
6. Location in a Western State, in an arid, low-population-density region

Table 5-4. Collective dose to the general population in the vicinity of a model mill *(5.5)*

Radionuclide	Source term[a] (mCi/y)	Pathway	Critical organ	Collective critical organ dose[b] (person-rem/y)
Uranium-234 and 238	180	Air	Lung	2.2
Thorium-230	15	Air	Lung	0.2
Radium-226	10	Air	Lung	0.1
			Total	2.5

[a] Releases to water pathways assumed equal to zero, and doses from radon-222 are not included.

[b] The population for the model mill assumes that 5.5×10^4 persons are exposed within 80 km of the mill site.

steel or zircaloy tubing which is then capped and welded into fuel rods. These completed fuel rods are assembled in fixed arrays into fuel elements which are installed into the reactor core.

Radioactive wastes discharged from fuel fabrication plants are quite limited. Most of the uranium waste compounds are solid and conventional air equipment is used to remove the particulates from the airborne effluents. Liquid effluents are collected in settling tanks or ponds. Estimates of the quantities of isotopes released from typical facilities based on limited monitoring information have been published *(5.9)*, and a summary of these estimates is given in table 5-9. Dose values have been estimated from these effluents and these are shown in table 5-10. The data indicate that the total body collective dose estimate from fuel fabrication operations is about 3×10^{-5} person-rad/MW(e)-y from liquid releases and 10^{-7} person-rad/MW(e)-y from gaseous releases.

Table 5-5. Summary of the estimated total body dose to adult individuals at locations of maximum exposure resulting per year of operation of 8.75 million SWU per year enrichment plants *(5.7)*

Exposure pathway	Dose (mrem)[a]
Gaseous effluents	
Immersion in air	3.9×10^{-7}
Contaminated ground surface	1.4×10^{-1}
Inhalation	2.9×10^{-2}
Ingestion	1.3×10^{-1}
Liquid effluents	
Drinking water	9.2×10^{-4}
Swimming	6.7×10^{-6}
Ingestion (aquatic food chains)	3.8×10^{-4}
Total	0.3

[a] From either gaseous diffusion or gas centrifuge.

The relative importance of various environmental pathways to population doses calculated for model facilities is given in table 5-11. External radiation exposures from contaminated air were found to account for only a small fraction of the dose from all facilities except the reprocessing plant where large quantities of ^{85}Kr are released. External exposures from contaminated ground are relatively important only for the facilities (UO_2 fuel fabrication and reprocessing) which release relatively large fractions of gamma-emitting particulates. Internal exposures from inhalation pathways accounted for from 66 to 99 percent of total-body population doses.

Ingestion of radioactivity via terrestrial food pathways is a particularly significant potential route in the case of uranium mills and UO_2 fuel fabrication plants. Since mills are typically located in areas which are not particularly suited for farming or dairying, ingestion

Table 5-6. Summary of the estimated contributions to individual total body and organ doses resulting from exposure to gaseous effluents released from a 8.75 million SWU per year enrichment plant during one year of operation *(5.7)*

Organ of reference	Maximum annual dose (mrem)	Contribution to dose (percent)		
		Uranium	^{99}Tc	^{106}Ru
Total body	0.4	86	13	
Bone	2.4	95	2	
Thyroid	.3	86	13	
Lungs	1.3	95	2	
Muscle	.3	82	13	
Kidneys	2.2	27	70	2
Liver	.3	61	25	2
Spleen	.2	82	13	3
Testes	.3	86	13	
Ovaries	.2	86	14	
GI tract	8.4	3	75	22

probably does not contribute as greatly to radiation doses as was estimated in this analysis. However, the use of land for cattle raising around current milling operations could mean that the consumption of meat could represent a significant pathway for internal exposure. Inhalation of radioactivity may be considered a significant pathway of exposure for all facilities.

The estimated population doses from model facilities are given in table 5-12. For all facilities, estimated doses to bone and lung were higher than those to other organs. Table 5-12 is based only on atmospheric releases. The liquid release, assumed only for the UO$_2$ fuel fabrication facility, was estimated to contribute 0.015 mrem/y to the total-body dose of an individual drinking 1.2 liters of water per day, eating 20 g of fish per day, and swimming 1 percent of the year. The dose of this individual was estimated to be 0.26 mrem/y. These individual doses would amount to an additional 15 person-rem to total body and 260 person-rem to bone for 10^6 persons so exposed.

Table 5-7. Summary of the estimated total body dose to the population from all pathways per year of operation of 8.75 million SWU per year enrichment plant *(5.7)*

Exposure pathway	Dose (person-rem)[a]
Gaseous effluents	
Immersion	7.4×10^{-7}
Contaminated ground surface	3.2×10^{-1}
Inhalation	5.8×10^{-2}
Ingestion	2.5×10^{-1}
Liquid effluents	
Drinking water	9.2×10^{-3}
Swimming	6.7×10^{-5}
Ingestion (aquatic food chain)	6.9×10^{-3}
Total	6.4×10^{-1}

[a] From either gaseous diffusion or gas centrifuge.

Table 5-13 gives the contributions of radionuclides to population doses. The potential exposure from ^{226}Ra from uranium mills is evident. Even with less conservative assumptions for food intake, this radionuclide is significant from the standpoint of inhalation. Airborne ^{226}Ra from dusts and tailings accounted for about 20 percent of the dose to lungs via inhalation. This analysis and others indicate the potential for relatively large exposure to individuals. Population doses are low because most current mills are located in sparsely populated areas relative to other fuel cycle facilities.

Table 5-14 shows the estimated dose data from a fuel fabrication facility by various exposure pathways. The data indicate that it is unlikely that fuel fabrication activity would increase levels of exposure in the general environment *(5.12)*.

Table 5-8. Summary of the estimated contributions to population total body and organ doses resulting from exposure to gaseous effluents released from 8.75 million SWU per year enrichment plant during one year of operation *(5.7)*

Reference organ	Estimated dose (person-rem)	Contribution of exposure pathway (percent)			
		Inhalation	Immersion in air	Contaminated ground surface	Ingestion
Total body	0.64	8.9	<0.1	53.1	37.9
GI tract	16.	0.1	<0.1	4.5	95.3
Bone	4.6	17.5	<0.1	10.1	72.3
Thyroid	0.62	8.4	<0.1	56.0	35.5
Lungs	2.6	82.3	<0.1	9.5	8.1
Muscle	0.62	9.5	<0.1	50.0	40.4
Kidney	4.2	11.0	<0.1	11.4	77.5
Liver	0.65	10.1	<0.1	40.4	49.4
Spleen	0.44	10.9	<0.1	42.6	46.4
Testes	0.64	8.5	<0.1	55.4	36.0
Ovaries	0.40	12.5	<0.1	34.1	53.3

Table 5-9. Estimated radioactive effluents from fuel fabrication operations *(5.10)*

	Radioactivity released (Ci/y)		Facility size (GW(e)-y)[a]	Normalized release (10^{-6}Ci/MW(e)-y)		Operation
	Airborne	Liquid		Airborne	Liquid	
U	0.04	1.2	27.5	1.5	44.0	conversion
	0.18	1.8	90.0	2.0	20.0	enrichment
	0.005	0.5	26.0	0.2	20.0	fabrication
^{226}Ra		0.09	27.5		3.4	conversion
^{230}Th		0.04	27.5		1.5	conversion
^{234}Th		0.26	26.0		10.0	fabrication
^{234}Pa		0.26	26		10.0	fabrication

[a] Plant capacities:

Conversion	5,000	tonnes U per y
Enrichment	10,500	tonnes SWU per y
Fabrication	900	tonnes U per y

Table 5-10. Collective dose estimates for release from fuel fabrication operations *(5.10)*

		Collective dose factors (person-rad/Ci)						
	Uranium release	Total body	Bone	Liver	Kidney	Lung	Thyroid	G.I. tract
	Airborne	0.6	6.6	0.4	1.6	4.9	0.6	0.4
	Liquid	1.5	26.0					
Operation	Uranium release (10^{-6} Ci/MW(e)-y)	Collective dose (10^{-3} person-rad/MW(e)-y)						
		Total body	Bone	Liver	Kidney	Lung	Thyroid	G.I. tract
	Airborne							
Conversion	1.5	.0009	.0099	.0006	.0024	.0074	.0009	.0006
Enrichment	2.0	.0012	.0132	.0008	.0032	.0098	.0012	.0008
Fabrication	0.2	.0001	.0013	.0001	.0003	.0010	.0001	.0001
	Liquid							
Conversion	44.0	.066	1.14					
Enrichment	20.0	.030	.52					
Fabrication	20.0	.030	.52					
Total collective dose (person-rad/MW(e)-y)		.00013	.0022			.000018		

Table 5-11. Terrestrial pathways contributing to total-body population doses within 80 km of fuel cycle facilities *(5.9)*

Facility	Percent of total-body dose			
	Submersion in air	Contaminated ground[a]	Inhalation[b]	Ingestion[c]
Mill	<0.1	0.2	4.9	94.8
Fuel fabrication				
UO_2	<0.1	31.9	18.6	49.4
Mixed oxide	<0.1	1.0	98.1	0.8
Fuel reprocessing	21.6	12.0	56.5	9.9

[a] No shielding assumed, 24 h/day exposure.

[b] 20 m^3/day intake.

[c] All food is produced in area of exposure; daily intake is 300 g of meat, 250 g of vegetables, 1 liter of milk, and 1.2 liters of water.

Table 5-12. Estimated radiation doses[a] (person-rem) to population within 80 km of model fuel fabrication facility *(5.9)*

Reference tissue	Mills	UO_2	Mixed oxide
Total body	4.4	0.06	0.01
Organs			
Bone	46.7	0.66	0.43
Liver	5.2	0.04	0.05
Kidney	7.9	0.16	0.05
Thyroid	4.4	0.06	0.01
Lung	8.9	0.49	0.07
GI tract	4.1	0.04	$< 10^{-3}$

[a] Fifty-year internal dose commitment for 1 year of intake.

[b] Population around mill is 5.3×10^4 persons; for other facilities it is 3.56×10^6 persons.

Table 5-13. Percent contribution of radionuclides to total-body and organ doses of populations around model fuel fabrication facilities *(5.9)*

Reference tissue	Mill	UO_2	Mixed oxide
Total body	^{226}Ra(93.3) ^{230}Th(5.0)	U(94.2)	Pu(93.6)
Bone	^{226}Ra(83.4) ^{230}Th(13.2)	U(99.4)	Pu(97.5)
Liver	^{226}Ra(78.9) ^{210}Po(9.1),^{210}Pb(6.0)	U(96.1)	Pu(94.7) ^{241}Am(5.2)
Kidney	^{226}Ra(51.6),^{210}Po(19.1) ^{230}Th(17.3),^{210}Pb(11.2)	U(99.3)	Pu(90.9) ^{241}Am(7.7)
Lung	^{226}Ra(49.6) ^{222}Rn(45.6)	U(98.0) U(94.2)	Pu(96.7)
Thyroid	^{226}Ra(98.0)	U(94.2)	Pu(93.6)
GI tract	^{226}Ra(93.6)	U(86.0) ^{234}Th(7.0)	Pu(95.0)

[a] Radionuclides contribute 5 percent or more to doses.

Table 5-14. Estimated doses from fuel fabrication facility operations *(5.11)*

Type of dose	Inhalation pathway Lung	Drinking water pathway Bone	Drinking water pathway Soft tissue
Maximum dose to individual at plant boundary (mrem/y)	10	0.6	0.6
Average individual dose (mrem/y)	[a]0.002	[b]0.06	[b]0.006
Aggregate population dose (person-rem/y)	[a]3	[a]34	[a]3

[a]Within 80 km of facility.

[b]Within 300 of facility.

Power Reactors

In 1974 there were 44 civilian nuclear power reactors operating in 18 States. Radiation from reactors reaches the environment either as direct radiation, which may be of significance relatively close to the reactor boundary, or through discharges of low level, radioactive, gaseous and liquid wastes. For this reason, the environment is monitored.

Description of data base

The National Environmental Policy Act of 1969, requires that the Nuclear Regulatory Commission (NRC) prepare an Environmental Impact Statement for each nuclear power plant. This document contains data on baseline levels of radioactivity in the environment and also estimates the radiation dose to the public that results from normal plant operation.

After an operating license is granted, the licensee is required, under Title 10, Part 50 of the Code of Federal Regulations *(5.13)*, to file an operating report semiannually *(5.14)*. An environmental monitoring report may also be filed as part of the licensee's operating report or as a separate report. These reports are available to the public at NRC public document rooms.

Data acquisition for environmental reports is often accomplished by contracting firms specializing in performing environmental radiation surveys. The information required in environmental monitoring reports varies according to the technical specifications in the license of each nuclear reactor. The data generally include gross alpha, gross beta, and gamma-emitting radionuclides, ^{90}Sr, ^{89}Sr, and ^{3}H concentrations in samples of air, air particulates, surface water, ground water, drinking water, sediment, milk, and food products which are grown locally. External dose is usually measured with thermoluminescent dosimeters which are placed at various locations around the reactor consistent with meteorology.

State agencies frequently perform environmental radioactivity surveillance around nuclear power facilities in the interest of protecting the public health of their residents. These programs vary in sampling and analysis protocol, depending upon the number and type of facilities in the State. A summary of these programs has been published in references *5.15* and *5.16*.

Surveillance guidance has also been published by NRC in Regulatory Guide 4.1 *(5.14)*. In addition, the EPA Office of Radiation Programs has published a guide *(5.17)* which recommends a protocol for environmental radiation surveillance. The Atomic Industrial Forum has also published a treatise on radiological environmental monitoring which also includes ecological monitoring *(5.18)*.

A joint field study by EPA and NRC *(5.19)* was conducted during 1973 to measure iodine-131 in environmental samples of air, rainfall, vegetation, and milk collected around the Dresden, Monticello, and Oyster Creek nuclear power plants. Data from this field study were compared with levels of radioactivity in samples that were predicted by mathematical models with a view of determining the validity of the models.

A comprehensive radiological surveillance study conducted by EPA at the Haddam Neck nuclear power station *(5.20)* measured radionuclide concentrations in the environment and external radiation doses around the pressurized water reactor (PWR) facility. This study followed the techniques of similar studies conducted at the Dresden boiling water reactor (BWR) *(5.21)*, and Yankee-Rowe PWR *(5.22)*. Another study by EPA at the Shippingport Atomic Power Station *(5.23)* measured iodine-131 and strontium-90 concentrations in milk and soil, and ambient radiation levels in air.

Figures 5-7 to 5-10 are graphs that have resulted from an EPA study of reactor effluents. These figures show the differences in the degree of environmental contamination that can be expected from the operation of BWR's and PWR's *(5.24)*.

Dose data

Dose information is sometimes reported in semiannual reactor operating reports, for locations at or outside the site boundary. Dose measurements at Haddam Neck during 1971 *(5.20)* resulted in an estimation that an adult at the nearest residence received 0.5 mrem/y from airborne effluents. The maximum potential dose from the ingestion of indigenous fish was estimated to be 0.13 mrem/y - whole body and 0.25 mrem/y to the bone. The dose at ground level, 0.6 km from the vent, was estimated to be 0.2 mrem/y.

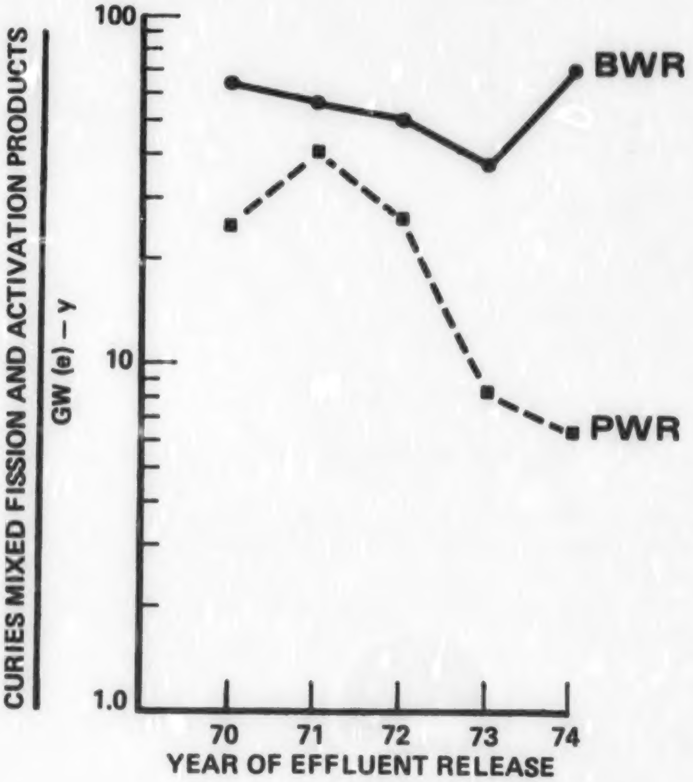

Figure 5-7. Trends in the release of mixed fission and activation products from light water-cooled nuclear reactors *(5.24)*

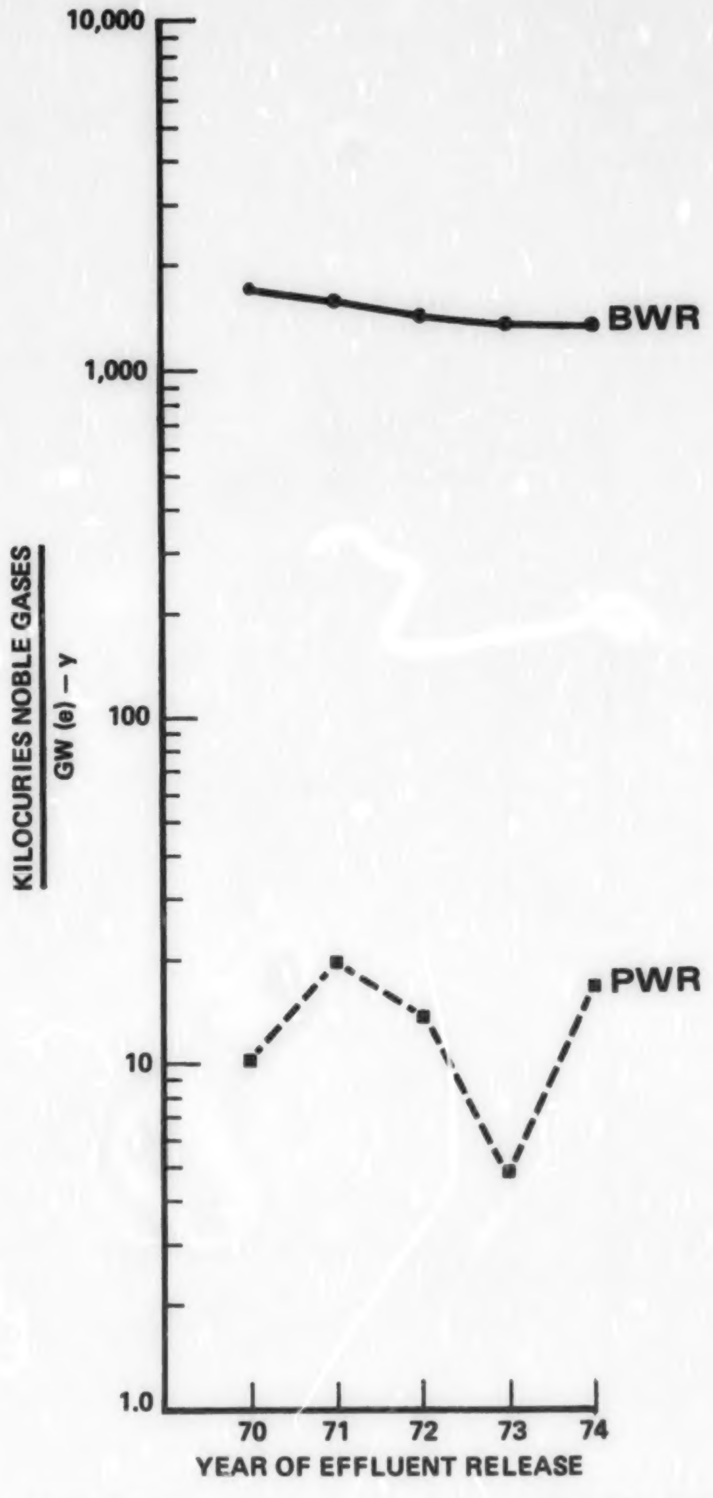

Figure 5-8. Trends in the release of noble gases from light water-cooled nuclear reactors *(5.24)*

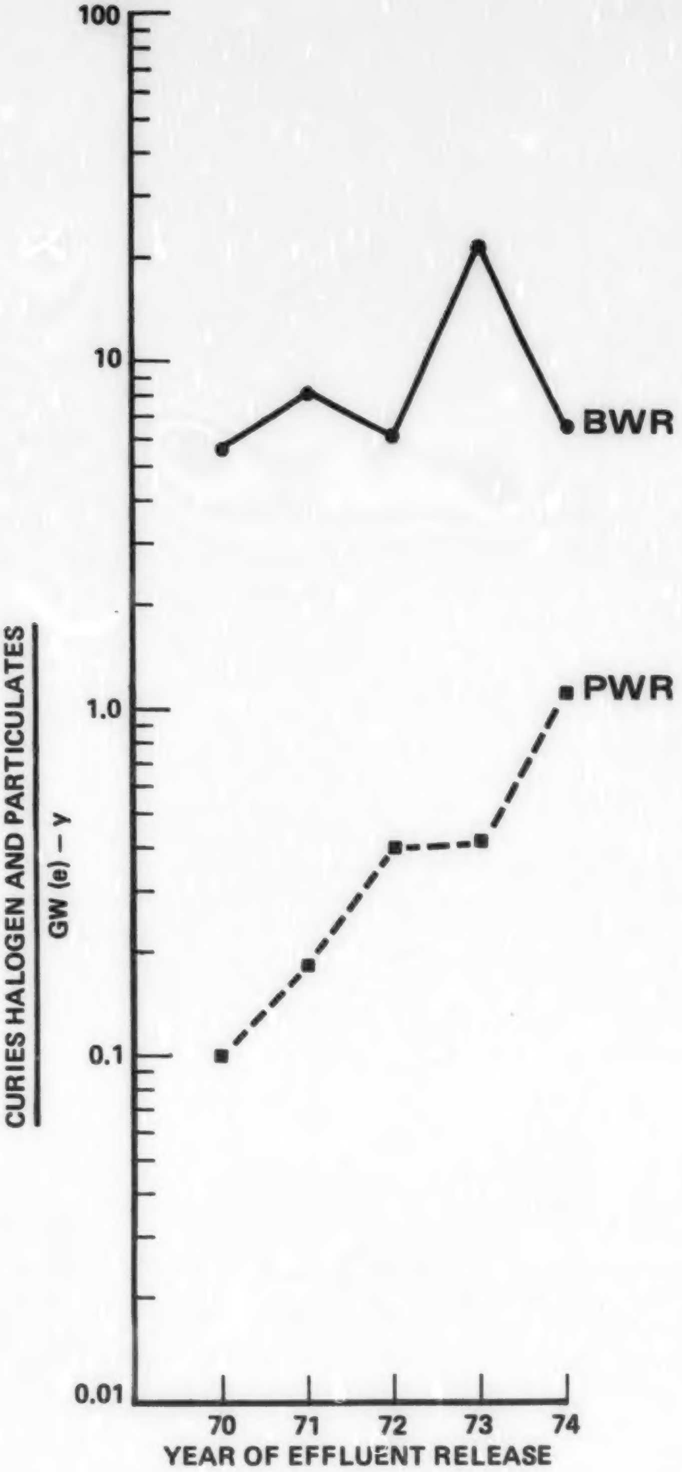

Figure 5-9. Trends in the release of halogens and particulates from light water-cooled nuclear reactors *(5.24)*

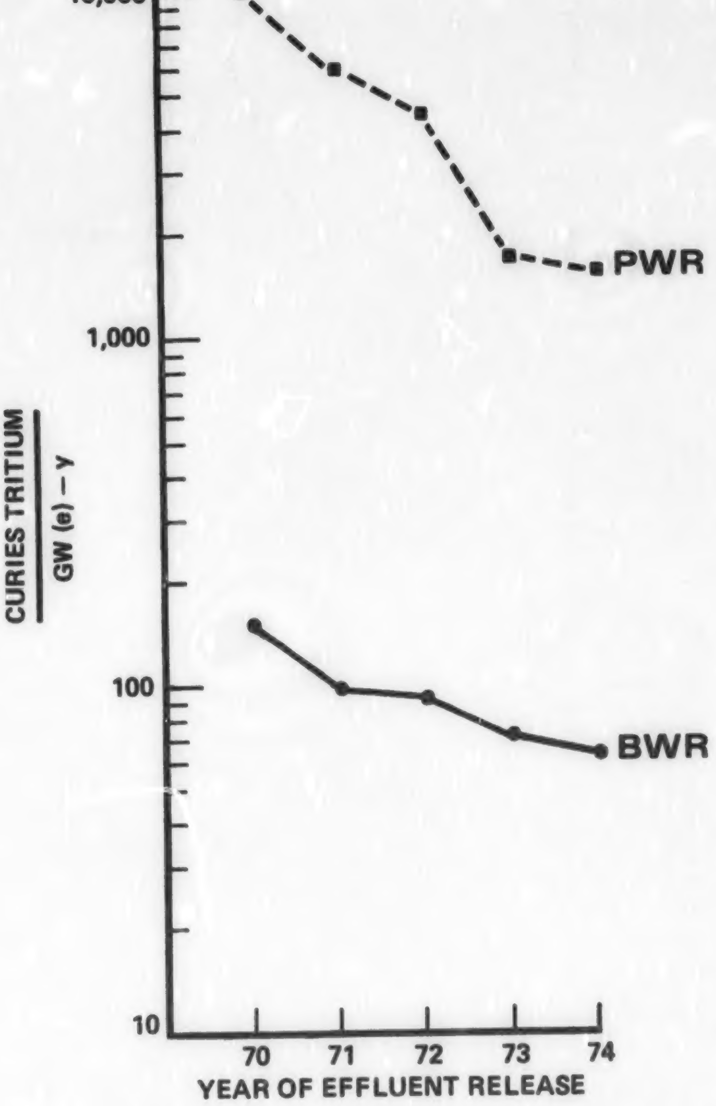

Figure 5-10. Trends in the release of tritium from light water-cooled nuclear reactors *(5.24)*

Table 5-15 lists operational and total body population dose data which were calculated from gaseous effluent data reported by NRC for BWR's *(5.25)*.

Table 5-15. Population dose, demographic and operational data for BWR's

	1971	1972	1973	1974
Number of BWR operating plants[a]	10	14	14	14
Energy generated (MWe-y)	1850	3400	4580	3890
Noble gases discharged (curies)	[b]3(6)	4.9(6)	6.2(6)	5.8(6)
Population dose from noble gases (person-rem)	900	1646	1564	1564
Population exposed[c]	16(6)	22.5(6)	22.5(6)	22.5(6)

[a] Although 18 plants were in operation, only 14 were considered for this tabulation.

[b] 3(6) = 3×10^6

[c] Population within 80-kilometer radius of each plant.

The New York State Department of Health *(5.26)* measured gaseous effluents from one BWR, two PWR's and one high temperature gas-cooled reactor (HTGR). From these data, they estimated the following doses at 1 km from a theoretical 2500 MW(t) reactor.

	Dose (mrad/y)		
	^{3}H	^{14}C	^{37}Ar
BWR	4×10^{-3}	6×10^{-2}	4×10^{-3}
PWR	2×10^{-3}	$>4 \times 10^{-1}$	1×10^{-2}
HTGR	1.2×10^{2}	<1	1.4×10^{2}

Other reports, while not presenting data for 1973, discuss dose commitment to populations from discharge of carbon-14 and krypton-85 *(5.27)* and from the nuclear power industry in the United States *(5.28, 5.29)*.

As mentioned previously, environmental impact statements (EIS) compiled by the NRC contain estimates of predicted radiation doses to the public from normal operation of nuclear power reactors. These estimates are summarized in a report by the Office of Radiation Programs of EPA *(5.30)*. Table 5-16 lists the calculated maximum doses at the site boundary based on discharges of gaseous effluents for the years 1972, 1973, and 1974 and the maximum whole body doses as estimated in the EIS's. The large differences between the predicted dose values and the dose values calculated from actual discharge information may be due to differences in the assumptions used in the calculations. It may be seen in comparing these doses that the calculated doses for BWR's are generally higher than the predicted doses given in the environmental impact statements. The reason for these differences is still being investigated.

Summary

Power reactors contribute to environmental radioactivity either through direct radiation from the reactor which is generally significant within the reactor boundary or through discharges of radioactive gaseous and liquid wastes resulting from reactor operations. The total population dose from the gaseous effluents of BWR's for 1974 has been estimated to be 1564 person-rem within a radius of 80 kilometers from each plant. The estimated population dose from PWR's is 21.4 person-rem, a significantly lower dose due to the large reduction in the release of radioactive gaseous effluents.

Research Reactors

At the end of 1975, there were 68 research and test reactors of all types exclusive of those owned by the Energy Research and Development Agency (see chapter 6 for discussion of ERDA facilities). Of these, 1 was an irradiation test reactor; 2 were high power research and test reactors; 14 were general research reactors, and 51 were classified as university research and testing reactors *(5.31)*. The rated power output of the reactors ranged from near 0 to 50,000 kW(t).

Research reactors are regulated by the Nuclear Regulatory Commission *(5.13)*, and the licensees are required to submit annual environmental monitoring reports. These reports are usually included in the reactor operating report and amount to a short paragraph stating the general condition of the environmental monitoring program. The reports are available to the public at the NRC public document room nearest the reactor. The most detailed description of the monitoring program for a research reactor can be found in its Final Safety Analysis Report which is filed with the NRC. Typical surveillance programs include gross beta measurements of water and air samples, and direct gamma dose measurements using thermoluminescent dosimeters.

Table 5-16. Calculated doses from noble gas releases at operating plants (1972-74)

Facility (Site)	Start up	Net site Capacity [GW(e)]	Annual output (% of capacity)			Site boundary dose (mrem/y)			Predicted exposure Gaseous (Whole body) (mrem)
PWR's			1972	1973	1974	1972	1973	1974	
Yankee Rowe	8/60	0.18	40	68	60	<1	<1	<1	NA
Indian Point 1 & 2	8/62, 5/73	1.14	16	24	50	<1	<1	1	[a]2
San Onofre 1	6/67	0.43	74	60	84	3	2	<1	[a]<1
Haddam Neck	7/67	0.58	85	46	89	<1	<1	<1	<1
R. E. Ginna	11/69	0.47	57	87	52	2	<1	<1	<1
Point Beach 1 & 2	11/70, 5/72	0.99	70	67	77	<1	<1	2	1
H. B. Robinson	9/70	0.70	72	82	87	<1	<1	<1	<1
Palisades	5/71	0.70	32	41	1	<1	<1	<1	<1
Surry 1 & 2	7/72, 3/73	1.58	6	65	45	<1	<1	[b]8	<1
Turkey Point 3 & 4	10/72, 6/73	1.39	--	62	66	--	<1	<1	<1
Maine Yankee	10/72	0.79	7	58	52	<1	<1	<1	<1
Oconee 1, 2 & 3	4/73,11/73,9/74	0.88	--	47	52	--	<1	3	[a]1
Zion 1 & 2	6/73, 12/73	1.05	--	22	39	--	<1	NA	[c]1
Ft. Calhoun	8/73	0.46	--	42	60	--	<1	<1	<1

Table 5-16. Calculated doses from noble gas releases at operating plants (1972-74), continued

Facility (Site)	Start up	Net site Capacity [GW(e)]	Annual output (% of capacity)			Site boundary dose (mrem/y)			Predicted exposure Gaseous (Whole body) (mrem)
BWR's			1972	1973	1974	1972	1973	1974	
Dresden 1	10/59	0.20	65	33	21	13	12	<1	<1
Big Rock Point	9/62	0.07	57	68	54	5	4	3	NA
Humboldt Bay	2/63	0.07	62	77	67	67	47	77	NA
LaCrosse	7/67	0.05	60	46	79	<1	3	2	NA
Oyster Creek	5/69	0.64	78	64	67	37	32	11	<1
Nine Mile Point	9/69	0.63	59	68	62	11	22	16	[d]<1
Dresden 2 & 3	1/70, 1/71	1.62	57	64	48	2	5	4	<1
Millstone 1	10/70	0.65	55	34	63	8	2	23	[e]<1
Monticello	12/70	0.55	75	68	62	30	31	67	1
Quad Cities 1 & 2	10/71, 4/72	1.60	28	73	57	<1	4	5	4
Vermont Yankee	3/72	0.51	10	44	56	3	4	1	<1
Pilgrim 1	6/72	0.66	15	71	34	<1	2	5	[f]<1

[a] Predicted values are for 3 units.

[b] Unusual high dose due to operating problems with recombiner which resulted in shorter holdup times and higher than normal releases.

[c] Predicted value is for 2 units.

[d] Includes the contribution from Fitzpatrick. The site gamma dose assumes 100 hours per year, in a boat, at point of nearest approach.

[e] One BWR & 2 PWR units.

[f] One BWR & 1 PWR unit.

NA = Not available.

In addition to the surveillance performed by the licensees, the States in which the reactors are situated maintain environmental monitoring programs in the vicinity of each site *(5.15,5.16)*. Because of the diversity of types and the variation of power output of these reactors, the surveillance that the States perform at the sites varies widely.

There is little or no published information on dose to the public or special surveillance studies carried out by government agencies.

Transportation

Authority

The two agencies having overlapping regulatory authority for the transportation of radioactive materials are the Department of Transportation (DOT) and the Nuclear Regulatory Commission. A memorandum of understanding defining the roles of these two agencies in the transportation of radioactive materials was signed on March 22, 1973.

Postal shipments are under the jurisdiction of the U.S. Postal Service (39 CFR 123-125). Shipments not in interstate or foreign commerce are subject to control by a State agency in most cases *(5.32)*. International shipments usually are made consistent with the standards of the International Atomic Energy Agency (IAEA), with DOT serving as the USA "competent authority" *(5.33)*.

Transportation of radioactive materials in the nuclear power industry

In WASH-1238, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, " AEC analyzed the potential impact on the environment of transporting fuel and low-level solid radioactive wastes for single light-water-cooled nuclear power plants. AEC determined that, under normal conditions of transport, the radiation dose to the individual receiving the highest exposure is unlikely to be more than 500 mrem/y and the average radiation dose to those individuals in the highest exposed group is about 100 mrem/y *(5.34)*. The cumulative radiation dose to all transport workers is about 4 person-rem per reactor-year, to other persons about 3 person-rem per reactor-year distributed among approximately 600,000 people *(5.35,5.36)*. AEC felt this generic analysis would serve to implement section 102(2)(c) requirements of the National Environmental Policy Act of 1969 (NEPA), under which applicants for an AEC license to operate light-water nuclear power plants must evaluate the environmental impact of transportation of nuclear fuel and low-level solid radioactive wastes to and from the plant. WASH-1238 served as the primary data base for the AEC amendment to 10 CFR 51 which permits the reactor licensing applicants in their environmental reports and AEC in their environmental impact statements to state that the adverse impact results from the transportation of spent fuel and packaged wastes from reactors falls within the values contained in the regulations *(5.36)*.

The amendments to 10 CFR, Part 51 (§51.20(g), Summary Table S-4 (table 5-17) and §51.23(a)) became effective February 5, 1975 (40 FR 1005-1009, January 6, 1975). In Supplement I to WASH-1238 *(5.37)*, NRC presents data and identifies the methods used in deriving the values contained in the regulations (Summary Table S-4). The values in Summary Table S-4 are those derived for the "typical" nuclear power reactor described in WASH-1238, with the exception of the cumulative dose values which are based on data tabulated from an individual analysis by NRC of the environmental impact of transportation for 84 individual nuclear power reactors at 53 different sites for the period January 1972 through March 1973.

The Environmental Protection Agency has agreed that the values in the transportation impact table (Summary Table S-4) in 10 CFR 51 are reasonable for the routine impact of normal transportation; however, the Agency feels that the impact resulting from transportation accidents or incidents is not clearly defined *(5.38, 5.39)*. The DOT and AEC philosophy regarding transportation safety is that safety is provided through the use of special shipping containers. EPA feels that the relationship between packaging test requirements and the survival of such packages under various accident conditions has not been established.

Special Studies

Holmes and Narver, Inc., in a study for EPA, made a quantitative assessment of the accident risks associated with the transportation of radioactive materials in the nuclear power industry for the period 1975-2020 *(5.40)*. The radioactive materials considered in the report were spent fuel, plutonium, high-level radioactive solid waste, and fission product gases. The consequences of accidents evaluated were radioactivity released and population doses. Methods of transportation considered were truck, rail, and barge. The study determined that the public health risks from the release of radioactivity from transportation accidents in the industry is relatively small because of the low probability of accidents, the small fraction of the accidents resulting in the release of radioactivity and because the majority of releases are relatively small fractions of the radioactive contents. Nevertheless, the amount of radioactivity accidentally released is sufficient to raise issues of public concern. The report also states there are very little statistical data on which to assess the risk of release of radioactivity from the shipment package as a result of an accident during transportation. Within the United States over the past 25 years, there have been about 300 reported accidents in transportation involving packages of all kinds of radioactive material. About 30 percent of those accidents

Table 5-17. Summary Table S-4. Environmental impact of transportation of fuel and waste to and from one light-water-cooled nuclear power reactor[a] *(5.37)*

Normal conditions of transport

	Environmental impact
Heat (per irradiated fuel cask in transit)	250,000 Btu/h
Weight (governed by Federal or State restrictions)	73,000 lbs. per truck; 100 tons per cask per rail car
Traffic density	
Truck	less than 1 per day
Rail	less than 3 per month

Exposed population	Estimated number of persons exposed	Range of doses to exposed individuals[b] (per reactor-y)	Cumulative dose to exposed population (per reactor-y)[c]
Transportation workers	200	0.0 to 300 mrem	4 person-rem
General public			
Onlookers	1,100	0.003 to 1.3 mrem	3 person-rem
Along route	600,000	0.0001 to 0.06 mrem	

Accidents in transport

	Environmental risk
Radiological effects	Small[d]
Common (nonradiological) causes	1 fatal injury in 100 reactor-years; 1 nonfatal injury in 10 reactor-years; $475 property damage per reactor-year.

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[a] Data supporting this table are given in the Commission's "Environmental Survey Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972.

[b] The Federal Radiation Council has recommended that the radiation doses from all sources of radiation other than natural background and medical exposures should be limited to 5,000 millirem per year for individuals as a result of occupational exposure and should be limited to 500 millirem per year for individuals in the general population. The dose to individuals due to average natural background radiation is about 130 millirem per year.

[c] Person-rem is an expression for the summation of whole body doses to individuals in a group. Thus, if each member of a population group of 1,000 people were to receive a dose of 0.001 rem (1 millirem), or if 2 people were to receive a dose of 0.5 rem (500 millirem) each, the total of person-rem dose in each case would be 1 person-rem.

[d] Although the environmental risk of radiological effects stemming from transportation accidents is currently incapable of being numerically quantified, the risk remains small regardless of whether it is being applied to a single reactor or a multi-reactor site.

involved release of radioactive material from medical and industrial radiochemicals. The report states that none of these accidents resulted in perceptible injury or death attributed to the radiation aspects and that there have been no releases from nuclear power shipments. Holmes and Narver estimate that nuclear power transportation activity will exceed one million miles in 1980 and 10 million miles after 2000.

Using current statistics, Holmes and Narver estimated there will be 1.3 accidents per million vehicle miles in 2020, with total accident frequency less than one per year in 1975, then increasing to one per month after 2000, and reaching almost two per month in 2020.

Up until about year 2005, spent fuel transportation will dominate. Plutonium transportation increases dramatically after 1995 and exceeds spent fuel transportation after 2005. Shipment of radioactive waste does not exceed 10 percent of the total until after 2000; shipments of radioactive gases comprise less than 2 percent of the transportation activity.

Holmes and Narver estimated the amount of radioactivity released from the transportation activity in the nuclear power industry from 1975 to 2020 based on transportation data, estimates of the fraction of radioactivity released during an accident, and the fractions of accidents of given severity associated with damages of given severity. These results were averaged by transportation mode, accident severity, release probability, and package damage severity. The estimated average annual releases of radioactivity are summarized in table 5-18, with the largest average release of radioactivity occurring from spent fuel. The average annual whole body population dose associated with transportation accidents is shown in figure 5-11 for the period 1975-2020.

Risk of transporting radioactive materials through large metropolitan areas

In May 1976 Sandia Laboratories, Albuquerque, New Mexico, began a 2-year study for NRC to assess the risk of transporting radioactive materials near and through a large metropolitan area. The main objective of this study is to prepare a generic environmental assessment of the possible radiologic, nonradiologic, and economic impacts on a densely populated, urban area produced from transportation of all radioactive material to and through such an area. Important factors such as city demography, local meteorology and the effects of buildings will be treated in the risk analysis. A model will be developed that is suitable to analyze radioactive material transport through any large city. Both normal and accident impacts will be considered, with the final assessment to include health effects. Under the present schedule, a final report should be available about June 1978 *(5.41)*.

Table 5-18. Estimated average annual release of radioactivity *(5.40)*

Year	Average annual release (Ci)					
	Spent fuel			Plutonium	High-level radioactive solid waste	Noble gas
	^{85}Kr	^{131}I	Fission product			
1975	0.55	7.4×10^{-6}	0.16	3.5×10^{-4}		
1980	1.4	2.0×10^{-5}	0.46	9.5×10^{-4}		
1985	2.9	3.7×10^{-5}	0.93	2.1×10^{-3}	6.5×10^{-3}	0.27
1990	5.7	4.4×10^{-4}	1.4	2.9×10^{-3}	1.7×10^{-2}	0.76
1995	8.8	2.7×10^{-3}	2.2	4.4×10^{-3}	3.7×10^{-2}	1.8
2000	10	8.9×10^{-3}	3.4	7.6×10^{-3}	6.7×10^{-2}	3.8
2005	12	1.7×10^{-2}	4.4	1.1×10^{-2}	8.6×10^{-2}	5.9
2010	13	2.2×10^{-2}	5.5	1.4×10^{-2}	0.12	7.6
2015	13	2.7×10^{-2}	5.9	1.6×10^{-2}	0.16	10
2020	13	3.1×10^{-2}	6.3	1.7×10^{-2}	0.19	11

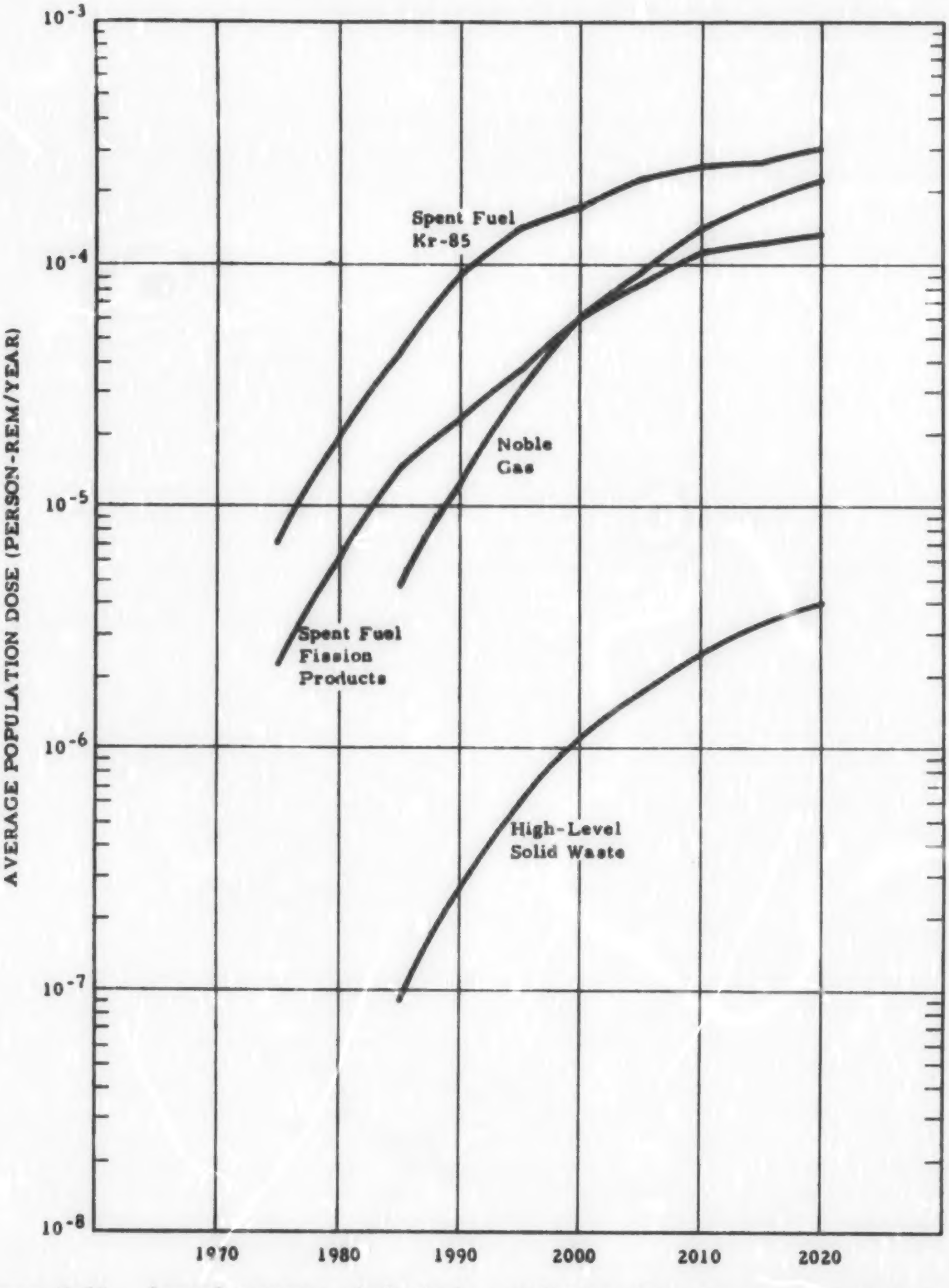

Figure 5-11. Annual average whole body population dose from transportation accidents in the nuclear power industry *(5.40)*

Transportation by air and other modes

In March 1976, NRC issued a draft generic environmental impact statement (NUREG-0034) on the air transportation of radioactive materials, including packaging and related ground transportation. Although directed at air transportation, other transportation modes--land and water transport--are considered. Weapon shipments and all shipments in government-owned vehicles were considered to be outside the scope of this document *(5.42)*.

The statement is intended to serve NRC as background material for a re-evaluation of its present regulations governing air transportation of radioactive materials, to provide sufficient analysis to determine the effectiveness of the present rules and of possible alternatives to those rules, and to respond to current national discussion of safety and security aspects of air shipments of plutonium and other special nuclear materials through highly populated metropolitan areas.

A list of standard shipments was compiled (table 5-19) based on a representative list of shipments as of July 1, 1975. The majority of packages of radioactive material shipped today contain radiopharmaceuticals. An estimated 600,000 packages were shipped in 1974. Three materials, molybdenum-99, technetium-99m, and iodine (including the isotopes ^{123}I, ^{125}I, and ^{131}I) accounted for over 75 percent of the packages shipped. For this report, NRC grouped all other radiopharmaceuticals into one group called "RAPH".

In its statement NRC concluded that the total annual population exposure resulting from normal transport of radioactive materials is about 9600 person-rem (table 5-20). The largest fraction of this population exposure (some 70 percent) results from shipment of medical-use radionuclides with industrial shipments (about 20 percent) and nuclear fuel shipments (10 percent) making up the remaining portion. The largest population exposure is from truck shipments because of the relatively long exposure times at low radiation levels of large numbers of people surrounding transport links. Individual radiation exposures are at generally low levels, only slightly above background radiation.

NRC's analyses determined that the radiation exposure from normal transportation averaged over the number of persons exposed amounts to 0.5 millirem per year, compared to the average natural background exposure of 100 millirem per year, resulting in a statistical increase of one latent cancer fatality per year in the United States from normal transportation of radioactive material. This compares to the existing rate of 300,000 cancer fatalities per year from all other causes. Abnormal transport occurrences would result in population exposure of 100 person-rem per year as an upper limit; actual exposures are expected to be lower. Alternatives to existing shipping practices for radioactive materials were found to produce only small changes in population exposure for normal transport.

Table 5-19. Standard shipments for the nuclear industry *(5.42)*

Shipment class	Avg. Ci/pkg	Avg. Transport Indices/pkg.	Total packages/year		Transport mode split - % of total			
			1975	1985	Pass. air & van	Cargo air & van	Truck	Rail
^{99m}Tc	0.28	0.1	1.14×10^5	2.96×10^5	100	--	--	--
Iodine Small	0.012	0.8	1.91×10^5	4.95×10^5	52.2	37.5	10	--
Iodine Large	56.7	1.6	1.00×10^3	2.59×10^3	--	100	--	--
^{99}Mo Small	0.60	2.4	1.01×10^5	2.62×10^5	32.5	32.6	34.9	--
^{99}Mo Large	80	3.6	7.20×10^3	1.87×10^4	--	100	--	--
[a]RAPH Small	0.042	0.5	1.33×10^5	3.45×10^5	52.5	37.5	10	--
[a]RAPH Large	74	1.7	2.70×10^3	7.00×10^3	--	100	--	--
^{192}Ir Source	100	5.0	6.6×10^3	1.71×10^4	--	--	100	--
^{192}Ir Raw material	5000	10.0	1.30×10^2	3.37×10^2	--	100	--	--
Spent Fuel SF Kr	2000 (Equiv.)	0	370	3.6×10^3	--	--	14.2	85.8
SF I	2 (Equiv.)	0	370	3.6×10^3	--	--	14.2	85.8
SF FP	800	100.0 (Equiv.)	370	3.6×10^3	--	--	14.2	85.8
PuO_2	3628	5.0	370	925	--	35	65	--

[a] All radiopharmaceutical other than molybdenum-99, technetium-99m, and iodine (including the isotopes ^{123}I, ^{125}I, and ^{131}I).

Table 5-20. Summary of radiological impacts of current shipments *(5.42)*

Standard shipment	Annual-pop. dose-normal trans.		Annual-pop. dose due to accidents	
	Dose (Person-rem)	Latent cancer fatalities	Organ	Latent cancer fatalities
^{99m}Tc	171	0.021	Lung	8.0×10^{-10}
Iodine-small	2779	.338	Thyroid	8.5×10^{-7}
Iodine-large	16	.002	Thyroid	8.5×10^{-7}
^{99}Mo-small	4240	.55	Lung	7.3×10^{-7}
^{99}Mo-large	299	.036	Lung	2.7×10^{-7}
[a]RAPH-small	1217	.148	Thyroid	2.1×10^{-6}
[a]RAPH-large	46	.006	Thyroid	3.0×10^{-6}
^{192}Ir-source	248	.030	Whole body	3.4×10^{-13}
^{192}Ir-raw material	5	.001	Whole body	6.5×10^{-13}
Spent fuel	535	.065	Thyroid, lung, bone marrow	7.3×10^{-8}
PuO_2	33	.004	Lung, bone	5.5×10^{-4}
TOTAL	9589 (9600)	1.166 (1.2)		5.58×10^{-4} (5.6×10^{-4})

[a] All radiopharmaceutical other than molybdenum-99, technetium-99m, and iodine (including the isotopes ^{123}I, ^{125}I, and ^{131}I).

Various Federal, State and local agencies were asked to comment on the report. NRC indicated the acceptance of doses to individuals from normal shipments on aircraft of 340 mrem/year (maximum) and 60 mrem/year (average). EPA issued recommendations to FAA in December 1974 for a dose rate limit of 0.5 mrem/h at seat level (42 mrem/y) since at least one cost effective method can be used to significantly reduce these doses (i.e., increased shielding) *(5.43,5.44)*.

Reprocessing Operations and Spent Fuel Storage

Spent fuel from nuclear power plants is reprocessed in order to recover isotopes of plutonium and uranium. The separation of these useful radionuclides from the spent fuel results in large quantities of radioactive waste products. Therefore, the waste management program is of great importance at a nuclear fuel reprocessing plant and the controlled discharge of low level wastes from the plant to the environment is very carefully monitored.

Since 1972, there have been no operating commercial reprocessing plants in the United States. The Nuclear Fuel Services plant in West Valley, N.Y., operated from 1966 to December 1971, but was shut down to expand its reprocessing capability to 750 metric tons of fuel per year. In September of 1976 Nuclear Fuel Services "notified NRC that they are abandoning plans to reprocess fuel" *(5.45)* because of economic reasons. In addition to the NFS plant in West Valley, N.Y., a reprocessing plant is under construction at Barnwell, S.C., but it is not expected to begin operation before 1978. The future of the Midwest Recovery Plant near Morris, Ill., is uncertain. It is now called the Morris Operation *(5.45)* and is used to store spent fuel. There are three noncommercial fuel reprocessing facilities operated for the U.S. government. These are under ERDA jurisdiction and are included with facilities discussed in Chapter 6 of this report.

Spent fuel is stored in special storage pools at power plants for varying periods of time before being shipped to a reprocessing plant. As a consequence of there being no commercial reprocessing plant in operation since 1972, more fuel is being stored at power plant storage facilities as well as at facilities at Morris, Ill. and West Valley, N.Y. The facility at Barnwell, S.C., is in the process of obtaining a license for spent fuel storage.

Description of the data base

Characterization of the gaseous and liquid effluents from nuclear fuel reprocessing plants shows the important radioactive components to be ^{14}C, ^{85}Kr, ^{129}I, ^{3}H, ^{106}Ru, ^{90}Sr, ^{134}Cs, ^{137}Cs, uranium and plutonium *(5.46,5.47)*. A general assessment of the effects of these effluents is given in three reports *(5.11,5.48,5.49)*.

Environmental monitoring reports are filed semiannually with the NRC *(5.13)* by the operators of reprocessing plants as a requirement for their operation. These reports are available to the public at NRC public document rooms. Where spent fuel is stored at nuclear power plants or reprocessing plants, the waste management procedures are combined in one program and, therefore, separate environmental monitoring reports are not required. The types of data that are required in the reports to NRC are included in the technical specifications of the operating license for the facility. At the NFS plant in West Valley, N.Y., the quarterly reports for 1971 and 1972 contain information on ^{131}I concentration in three milk samples and gross alpha and beta concentrations in samples collected at perimeter monitoring stations.

New York State Department of Environmental Conservation maintains a surveillance program at the NFS site and publishes an annual report which includes the data collected *(5.15,5.16)*. A summary of environmental surveillance through 1972 at NFS is included in a report by Terpilak and Jorgensen *(5.50)*. The Division of Radiological Health of the South Carolina State Board of Health has a preoperational surveillance program *(5.15,5.16,5.51)* at the Barnwell site.

Besides the sources of environmental monitoring data cited above, special studies have been carried out at the NFS site during its period of operation. Iodine-129 found in samples of milk, animals, and other environmental samples is the subject of several reports *(5.52-5.55)*. Measurements of environmental levels of radioactivity due to gaseous *(5.47,5.56)* and liquid *(5.46)* effluents were made in field studies by the EPA, Office of Radiation Programs. Aerial measurements of radioactivity were made periodically by the AEC *(5.57)*. Other surveys of environmental radiation from NFS have been conducted by New York State *(5.58-5.60)*.

Dose data

Dose data are generally lacking in environmental monitoring reports filed with the NRC by fuel reprocessing plant licensees. However, several studies made by government agencies have reported dose information based on plant effluent data and on field measurements.

A report by the Office of Radiation Programs, EPA, which develops the concept of environmental dose commitment to populations, projects doses over a 50-year period from 1970 to 2020 from normal operations of the nuclear power industry in the United States including fuel reprocessing plants *(5.28)*. Magno, et al. *(5.27)* estimates that population dose from ^{14}C may be significant. Russell and Galpin *(5.61)* in a review of offsite doses from fuel reprocessing plants indicate that radioactive iodine and krypton-85 are the most important gaseous effluent components in terms of dose to the public.

The Office of Radiation Programs of EPA in a report *(5.12)* estimating ionizing radiation doses in the United States from the year 1960 to 2000, includes dose data from reprocessing plants. The average annual dose (whole body) accrued to the population within 100 kilometers of a fuel reprocessing plant, reprocessing LWR fuel is calculated to be 0.17 mrem/person/y, and 6.3 mrem/person/y at a distance of 3,000 meters. A report by the NRC estimates the environmental impact of a model fuel reprocessing plant *(5.45)*. The impacts given are derived from the model fuel-cycle facilities used in the final generic environmental statement and the use of recycle plutonium in mixed oxide fuel in light water cooled reactors (GESMO). Based on this model plant the "total whole-body dose commitment to the world population from the reprocessing demanded by a single light water reactor in a year is about 600 person-rem" for the situation where uranium only is recycled.

Witherspoon *(5.9)* estimates the population dose from a hypothetical reprocessing plant to be 474 person-rem, (50-year internal dose commitment for 1 year of intake) whole-body, to the population within 80 km of the model facility.

Shleien *(5.62)* calculated whole-body doses using the individual dose commitment concept, i.e., the dose delivered (in mrem) to a critical organ during a 50-year period from a particular intake. The individual dose commitment was based on field measurements of environmental activity at the NFS plant site during 1968. For the "maximum individual," the whole-body dose commitment from ingestion of cesium-137 and cesium-134 (mostly from deer meat) was estimated to be 257 mrem. For the "typical individual," the whole-body dose commitment from cesium-137 was 1.7 mrem, and this was attributed mainly to the dose from fallout. Another study by Martin *(5.63)*, using effluent and environmental surveillance data from the NFS site for 1971, found the most significant radionuclides contributing to dose were tritium, krypton-85, strontium-90, cesium-137, and cesium-134. The average annual (for 1971) whole-body dose to individuals in the maximum exposure group was calculated to be 5.8 mrem and the whole body population dose was 23 person-rem. An in-depth survey of the intake of fish and venison caught in the vicinity of NFS in 1971 by Magno, et al. *(5.64)* resulted in the calculated maximum whole body individual dose from fishing to be 1.4 mrem and from ingestion of venison (in 1970) to be 14 mrem. These figures are considerably smaller than the doses estimated by Shleien for 1968 *(5.62)*.

The Environmental Impact Statement for the Barnwell reprocessing plant under construction predicts the maximum whole-body dose from normal plant operations to be 4 mrem/y *(5.30)*.

Summary

There has been no commercial fuel reprocessing plant in operation in the United States since December 1971. The Nuclear Fuel Services plant operated from 1966 to 1971, and the data reviewed in this report are for this plant during its period of operation.

Spent fuel is stored in special pools at individual nuclear power plants and at storage areas at NFS and Morris, Ill.

Dose estimates are generally not included in reports by spent fuel storage and reprocessing licensees. However, State and U.S. government agencies have collected data and reported dose information in several studies.

Reprocessing operations and spent-fuel storage is concerned with conducting a safe waste management program with a view of recovering selected isotopes and controlling the discharge of low-level wastes to the environment. It appears that the most significant radionuclides contributing to this dose are ^{3}H, ^{14}C, ^{85}Kr, ^{90}Sr, ^{134}Cs, and ^{137}Cs.

Radioactive Waste Management

General

The safe management of nuclear wastes may be the determining factor in the future role of nuclear power.

EPA views radioactive waste management in the broadest environmental sense--all matters and forms of radioactive waste present potential environmental and public health problems. EPA does not limit its definition of radioactive waste to only those wastes resulting from the production of power by nuclear reactors.

EPA has divided radioactive wastes into the following general classes or categories because of their markedly differing character, volumes, and treatment/disposition requirements: 1) high-level; 2) low-level; 3) transuranium-contaminated (TRU); 4) uranium mill tailings; 5) decommissioning of radioactive-contaminated facilities and areas; and 6) naturally occurring radioactive waste generated by nonnuclear energy industries, e.g., mining and processing of phosphate, coal, and other minerals *(5.65, 5.66)*.

Waste management, as defined by EPA has meant confinement; that is, assurance of the isolation of the waste from the environment (biosphere) for the duration of its hazardous lifetime. This may involve burial, storage, or some other form to assure that dispersion into the biosphere does not take place.

NRC has grouped the wastes from the nuclear fuel cycles for uranium-fueled reactors into six major classes: high-level wastes (HLW), transuranium-contaminated wastes (TRU), non-transuranium-contaminated wastes (often called low-level wastes-LLW), and contaminated facilities and equipment. Two special classes of wastes are spent fuel from the fuel cycle in which there is no recycling of uranium or plutonium (with no reprocessing) and unused plutonium from the uranium-recycle process *(5.67)*.

High-level wastes are defined in Appendix F, 10 CFR Part 50, as "aqueous waste resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated waste of subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels." Only the fuel cycles involving reprocessing generate HLW under this definition.

Low-level wastes may be either transuranic or nontransuranic in character--transuranic wastes have been measured or are assumed to contain more than a specified concentration (e.g., 10 nanocuries of alpha emitters per gram of waste) of transuranic elements (i.e., elements with atomic numbers larger than 92). Some of these nuclides are particularly toxic; some have very long half-lives (tens of thousands of years). Waste materials containing significant quantities of these long-lived elements require special long-term consideration. Solid wastes contaminated with transuranics (TRU) are derived primarily from operation of the fuel reprocessing plant.

Nontransuranic wastes (low-level wastes-LLW) are any radioactive waste material in which concentrations of alpha radiation-emitting isotopes are negligible. Maximum half-lives of the isotopes of concern are about 30 years, so that decay to innocuous levels occurs in hundreds of years, and isolation from the biosphere need not be for as great a period as for transuranic elements.

The long-term hazard associated with low-level and high-level waste is not necessarily proportional to the nominal level of radioactivity, but rather to the specific toxicity and decay rate of each radionuclide. From the standpoint of waste management, the most significant radionuclides decay with half-lives of months to hundreds of thousands of years.

Major facilities and the equipment they contain become radioactive wastes at the end of their useful life. The procedure of taking a major facility out of service is termed decommissioning. Decontamination procedures vary according to the type of facility and may include such actions as: 1) equipment removal; 2) removal of cell liners; 3) monitoring of all surfaces to assure adequate decontamination of the potentially hazardous radioactive material *(5.67)*.

Each facility or operation in the fuel cycle produces wastes. Uranium ore is obtained from both underground and open-pit mining operations. Wastes from underground mines consist mainly of rock removed in creating shafts and passageways. Wastes from open-pit operations consist largely of overburden removed to expose the ore body. Wastes from either operation are expected to contain only relatively small amounts of uranium. Mine waste should have essentially the background radioactivity typical of the region. A uranium mill extracts uranium from ore. During milling, 20 to 80 percent of the radon gas in the ore and small fractions of other nuclides are released to the environment.

Almost all of the radioactive decay products of the uranium ore end up in the tailings, mostly in the tailings solids, but with small percentages in solution. Large amounts of solid waste tailings remain following the removal of the uranium from the ore. A typical mill may generate 1800 metric tons per day of tailings solids slurried in 2500 metric tons of waste milling solutions. Over the lifetime of the mill, 100 to 200 acres may permanently be committed to store this material. Included in the tailings are 97 percent of the radioactive decay products of the uranium and about 4 percent of the original uranium. Uranium mill tailings piles are long half-life, low-level radioactive wastes. As such they will require perpetual care. Mining and milling wastes are discussed in more detail in another chapter.

High-level wastes management

Waste from federal facilities

More than 205 million gallons of high-level radioactive liquid waste has been generated over the past 30 years at ERDA (formerly AEC) facilities. The majority of this waste is stored at the Hanford Reservation in Washington and the Savannah River Plant near Aiken, South Carolina, with a small percentage at Idaho National Engineering Laboratory near Idaho Falls, Idaho *(5.68)*. ERDA's inventory of high-level radioactive waste in both liquid and solid form as of June 30, 1974, is presented in table 5-21.

Table 5-21. Inventory of high-level radioactive waste *(5.68)*

	Quantity (1000 gallons)		
Location	Solids	Liquids	Total
Richland	26,498	31,823	58,321
Savannah River	8,504	11,833	20,337
Idaho Falls	329	1,907	2,236
Total	35,331	45,563	80,894

The chemical reprocessing of fuel used in nuclear reactors is the largest source of radioactive wastes. This process generates gaseous, liquid and solid waste. Of all forms of waste, liquid containing high levels of radioactivity poses the most complex technical problems in management and the potentially most severe hazards.

High level wastes require a system for their management which provides radiation shielding, protection against release, and a means of heat dissipation.

Strontium-90, cesium-137, and plutonium-239 contained in high-level waste are of greatest concern. Each is hazardous in terms of its potential effects on the human body, the pathways by which it may reach the body, and the length of time it remains dangerous (table 5-22). These radionuclides cannot be neutralized. Strontium-90 and cesium-137 require about 600 years to decay to 1/1,000,000 of their original level of radioactivity. For plutonium-239, it takes about 500,000 years. These radionuclides can reach man through several pathways: air, water, contaminated vegetation and animals and products from animals (milk, cheese, etc.).

Table 5-22. Principal long-lived waste constituents *(5.69)*

Strontium-90

28.9-yr. half-life, fission product, β emitter
Specific activity: 142 Ci/g

Cesium-137

30.1-yr. half-life, fission product, γ emitter
Specific activity: 87 Ci/g

Plutonium-238

87.8-yr. half-life, α emitter
Specific activity: 17 Ci/g

Plutonium-239

24,390-yr. half-life, α emitter
Specific activity: 0.062 Ci/g

Waste management activities at these sites consists of containing the liquid in underground tanks pending solidification, solidifying the liquid to prevent leaks and reduce volumes, and developing methods of further immobilizing the solidified waste. Management practices vary at the three sites because of factors such as geology, weather and form of waste.

The solidification program consists of converting high-level liquid waste into salt cake at Richland and Savannah River and into calcine (a dry granular form) at Idaho Falls. Calcine and salt cake are not considered the most acceptable form for long-term storage because they are both water dispersible. A more acceptable form has not been demonstrated on a production basis.

ERDA has estimated that 60 million gallons of commercial high-level liquid waste will be generated (but not accumulated) by the year 2000 and 238 million gallons by 2020. This is in addition to the 205 million gallons generated by AEC over the past 30 years and approximately 7.5 million gallons ERDA presently generates each year *(5.68)*.

From the early 1940's until June 1974, AEC has experienced 26 leaks in underground storage tanks containing high-level radioactive liquid waste, 18 leaks occurring at Richland, releasing 430,000 gallons of waste into the surrounding soil. The remaining eight leaks have occurred at Savannah River, only one of which resulted in the release of waste into the surrounding soil. No leaks have occurred at Idaho Falls.

The principal deterrent to leaks from underground storage tanks is the program of solidifying the liquid to calcine or salt cake form. Table 5-23 shows the progress in reducing the volume of high-level waste inventory.

Table 5-23. Volume of high-level radioactive wastes at ERDA production sites *(5.68)*

	High level liquid waste (millions of gallons)			
Date	Idaho	Richland	Savannah River	Total
12-31-67	1.5	74.0	16.8	92.3
12-31-68	1.5	71.4	16.6	89.5
12-31-69	1.6	68.1	18.2	87.9
12-31-70	1.8	65.8	17.9	85.5
12-31-71	2.2	65.3	17.9	85.4
12-31-72	2.3	64.0	19.0	85.3
12-31-73	2.2	65.0	20.0	87.2
6-30-74	2.2	58.3	20.3	80.8

Waste from commercial facilities

Approximately 600,000 gallons of high-level liquid waste have been generated from commercial fuel reprocessing and are stored in underground tanks located on State-owned land at West Valley, N.Y. Nuclear Fuel Services was the first commercial fuel reprocessor in the United States, operating from 1966 until 1972. The contract between Nuclear Fuel Services and New York State expires in 1980 and neither plans to extend the contract. Two other commercial fuel reprocessors were scheduled to begin operations during the late 1970's. The Barnwell Nuclear Fuel Plant at Barnwell, S.C., is presently awaiting licensing; the G.E. Midwest Fuel Recovery Plant at Morris, Ill., encountered technical difficulties and it is doubtful whether it will operate.

Under the 1970 regulations issued by AEC (10 CFR 50, app. F) commercial reprocessors must convert liquid waste to an acceptable solid form not more than 5 years after it is generated (excepting the 600,000 gallons of liquid waste possessed by NFS)[1,2] and physical custody of the waste would be transferred to ERDA not more than 10 years after it is generated. From that point on, ERDA would provide permanent storage or disposal, with the cost to be borne by the reprocessors. Technology for ultimate disposal is still in the research stage. It has been estimated that the total volume of solidified high-level wastes produced by commercial nuclear power in the United States through the year 2000 will be equivalent to a cube about 70 feet on each side.

Low-level waste management

Background

AEC has used three methods of disposal of low-level radioactive wastes: dilution and dispersion, shallow land burial, and sea disposal.

Dilution and dispersion through release of effluents is still permitted under existing regulations but with increasing emphasis on maintaining such releases to the environment as low as reasonably achievable.

Sea disposal of low-level wastes was discontinued in June 1970. However, between 1946 and 1970, approximately 94,600 Ci of low-level packaged wastes were dumped at sea. Most of these wastes have long since decayed. The Atlantic and Pacific Oceans and the Gulf of Mexico were used for disposal of low-level wastes originating mostly from research and development facilities such as Brookhaven. In June 1960, the AEC initiated a phaseout of sea disposal by placing a moratorium on issuing new sea disposal licenses but allowing existing licenses to remain in effect. By 1970 the practice of sea dumping was discontinued, mainly because land burial is more economical, but also because of mounting pressure against sea disposal of any kind. EPA has the regulatory authority for issuing ocean disposal permits but has issued none since its formation in 1970. In 1974-1975, EPA conducted surveys of disused deep-ocean radioactive waste dumpsites to determine the fate of radioactive waste packages dumped there in past years and to make preliminary determinations concerning the distribution of any released wastes. These sites, located in the Atlantic Ocean off the Maryland-Delaware coast and in the Pacific Ocean near the Farallon Islands, had received the majority of all wastes dumped during the 1946-1962 period *(5.70-5.76)*.

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[1] An NRC proposed regulation specifically governing the management of NFS wastes is tentatively scheduled for publication in mid-1978.

[2] EPA and New York State in conjunction with the U.S. Geological Survey are developing an environmental pathway model to assess the impact of the waste burial site on the environment and man.

Since 1967, some European countries, principally the United Kingdom, have been disposing solidified low-level radioactive wastes into the deep ocean under the supervision of the Nuclear Energy Agency. However, this practice is presently limited to only a few countries with high population densities and/or limited land space, and is subject to restrictions of the International Ocean Dumping Treaty.

Shallow-land burial

During the early 1960's when the dangers of sea disposal of radioactive wastes became apparent, the AEC established a series of regional disposal sites "as needed" to be located on State-owned land or Federal property and some were licensed for operation by commercial enterprises.

The first commercial land burial site located at Beatty, Nevada, was licensed in September 1962 and five additional commercial sites were licensed by AEC and Agreement States by 1971. In May 1963 AEC stopped handling low-level wastes from private industry. The general guidelines for a burial license and the necessary environmental statement are given in NRC Regulations 10 CFR 20, 30, 40, 51, and 70.

At present there are six commercially-operated shallow-land burial sites located in West Valley, New York; Barnwell, South Carolina; Sheffield, Illinois; Maxey Flats, Kentucky; Beatty, Nevada and Richland, Washington (table 5-24). All but the Washington site are located on State-owned land, with the Washington site located on Federally-owned land leased to the State. Five of the burial sites are located within "agreement States" and are subject to State regulations (between the individual States and NRC). In the one nonagreement State (Illinois), NRC regulates the site. In addition to the six commercial facilities, there are five principal Federal land disposal sites controlled by ERDA located at Idaho National Engineering Laboratory, Idaho; Hanford Facility, Washington; Los Alamos Scientific Laboratory, New Mexico; Oak Ridge National Laboratory, Tennessee; and Savannah River Plant, South Carolina (figure 5-12). The hydrology, geology, geology and climate at the various commercially operated sites differ greatly, ranging from those located in temperate humid zones, to others situated in near-desert areas. Rainfall, which creates much of the eventual problem of waste leakage, ranges from as little as 2.5 inches per year to as much as 46 inches *(5.77,5.79,5.80)*.

Present sites receive a portion of their waste from the nuclear fuel cycle and the rest from hospitals, universities, ERDA, and other sources. Low-level wastes generated in the LWR fuel cycle fall into three categories: wet solid wastes, compactable, and noncompactable dry wastes. Present policies prohibit the burial of plutonium (except at the Hanford site) but some remains in place from previous years. The principal operations at a commercial land burial ground are the receipt, temporary storage, and burial in trenches of packaged radioactive wastes.

Table 5-24. Commercial waste burial grounds *(5.77)*

Location	Operator	Originally licensed by (year)	Currently licensed by	TRU accepted	Operational status
Beatty, Nev.	Nuclear Engineering Co., Inc. (NECO)	AEC (1962)	State & NRC*	<10 nCi/g	SNM license suspended
Maxey Flats, Ky.	NECO	Kentucky (1962)	State	<10 nCi/g	Open
West Valley, N.Y.	Nuclear Fuel Services	New York (1963)	State	0.1 g Pu/ft^3 other elements, yes	Closed
Hanford, Wash.	NECO	AEC (1965)	State & NRC*	Yes	Open
Sheffield, Ill.	NECO	AEC (1967)	NRC	<10 nCi/g	Open
Barnwell, S.C.	Chem-Nuclear Systems, Inc.	South Carolina (1971)	State & NRC*	<10 nCi/g	Open

*NRC licenses only special nuclear material (SNM).

The packages are normally buried as received, with no processing or repackaging of package contents. However, in some cases, the primary package containing the waste is shipped in a reusable over-pack or secondary container which may be required by Department of Transportation regulations for shipment of the particular materials involved.

An average burial trench at a commercial burial site is about 300 feet long, 40 feet wide, and 25 feet deep and has a volume of about 340,000 cubic feet. The volume is not completely utilized since there are voids between packages, and between packages and the earth-fill. (It is estimated that about 50 percent of the volume is utilized). The filled trenches are capped with a mound of earth to reduce infiltration from precipitation. However, because of individual site characteristics such practices and procedures as trench construction, waste placement, type and form of waste accepted, monitoring programs, water management, etc. may vary from site to site. In the wetter Eastern United States, precipitation presents operational problems. At two sites which have burial media with relatively low permeability, operational experience indicates that it is difficult to keep water from getting into the trenches *(5.81)*.

Until the early 1970's, no problems were identified in the regulation and operation of the commercial burial grounds. Problems subsequently arose at four sites: Maxey Flats, Ky; West Valley, N.Y; Beatty, Nev; and Sheffield; Ill. None of the problems has created a significant public health and safety problem *(5.77)*.

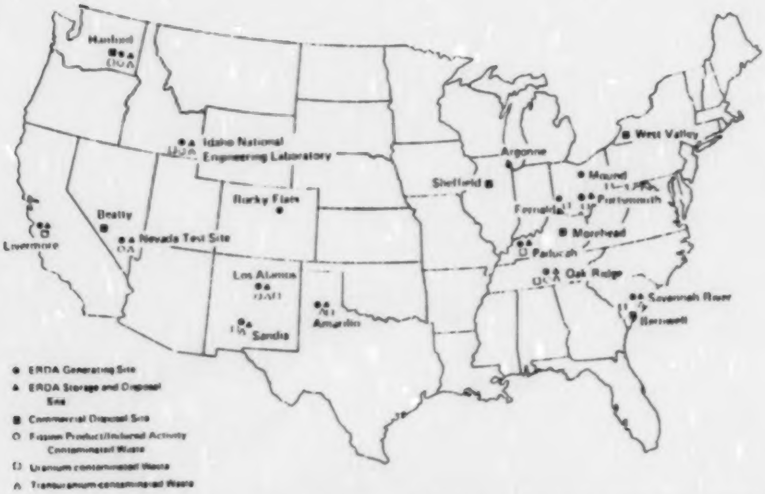

Hanford
Idaho National Engineering Laboratory
West Valley
Argonne
Sheffield
Mound
Portsmouth
Fernald
Rocky Flats
Beatty
Nevada Test Site
Livermore
Morehead
Paducah
Oak Ridge
Los Alamos
Amarillo
Sandia
Savannah River
Barnwell
● ERDA Generating Site
▲ ERDA Storage and Disposal Site
■ Commercial Disposal Site
○ Fission Product/Induced Activity Contaminated Waste
□ Uranium contaminated Waste
Λ Transuranium-contaminated Waste

Figure 5-12. Major generating, storage, and disposal sites for solid low-level radioactive waste *(5.78)*

In the early 1970's, Kentucky became concerned about the accumulation of water in completed trenches at Maxey Flats and at the increase in volume and quantity of waste being received at the site for burial. Studies indicated the burial ground was contributing radioactivity to the local environment; tritium, cobalt-60, strontium-89 and -90, cesium-134 and -137 and plutonium-238 and -239 were identified in individual samples in the unrestricted environment. The levels ranged from slightly above background to orders of magnitude above background for individual samples. A water management program has been instituted at the site to minimize the potential for migration of radioactivity. Kentucky has an extensive environmental monitoring program at the site, and several USGS research studies are currently underway. The Kentucky Legislature has imposed a 10 cents per pound excise tax on waste received at the site for burial, effective in June 1976. This tax makes the cubic foot charge at the site about three times the charge at other sites. As a result, the site is virtually unused.

In March 1975, NRC was informed of water seepage from two trenches at the West Valley, New York burial ground. Increased levels of tritium in water samples had been found in samples taken from onsite monitoring stations. The seepage was diverted to a holding lagoon and subsequently processed through NFS processing plants' low-level waste treatment system and released. No significant increase in radioactivity in the unrestricted environment was detected. Operations were suspended at the site and, as of December 1976, no agreement has been reached between State representatives and NFS regarding the conditions for reopening and operating the site. Several studies are being conducted by the State, EPA and USGS at the site.

In March 1976 the Nevada State Department of Human Resources initiated an investigation of the Beatty burial ground and uncovered evidence that violations of the operator's license had occurred over a period of years, involving removal of contaminated tools, equipment and supplies from the site by Nuclear Engineering Company (NECO) employees. The State suspended NECO's license on March 8, 1976, and NRC suspended its license on March 11, 1976. On May 25, 1976, the State lifted its suspension of NECO's license on the basis that emergency conditions had abated and that there was no significant hazard to the public health and safety in the vicinity of the disposal site. NRC will not take action to reinstate its license to NECO to dispose of special nuclear material at the Beatty site until completion of the Department of Justice investigation.

The present Sheffield, Illinois site is almost full unless new technology can be applied. Expansion of the site boundaries depends on the outcome of local rezoning hearings as well as NRC safety and environmental analyses.

Once a commercial site becomes filled to capacity, the licensee operator ceases to have responsiblity, the facility is decommissioned, and the responsibility for long-term care falls to the State government, although responsibility for the Hanford site will eventually revert to the Federal government *(5.80)*. One of the recommendations of the NRC Task Force reviewing the Federal-State regulation of burial grounds was the establishment of a Federally administered perpetual care program of the sites which can be accomplished through Federal land ownership *(5.77)*. It is recognized that requirements for effective site decommissioning, site care and further uses of the site are important aspects of shallow land burial. To date no commercial or ERDA site has been decommissioned.

Current volume and future projection of waste

Currently, about 2.5 million cubic feet of wastes are buried each year. The approximate cumulative totals of wastes buried through the end of 1975 are shown in table 5-25 *(5.77)*.

Table 5-25. Cumulative total volume and quantities of commercial waste buried through 1975 *(5.77)*

Volume (ft^3)	13,100,000
Byproduct material (curies)	3,300,000
Source material (kg)	680,000
Special nuclear material (kg)	1,056
Plutonium (kg)	113

Figure 5-13 shows several projections for expected generation of non-TRU wastes from 1975 through the year 2000.

The nonfuel cycle generation (curve C) are staff estimates based on the following generation rates:

Estimated nonfuel cycle
Medical/industrial/academic

Year	Generation rate (10^6 cubic feet)
1975-80	1
1981-85	1 1/2
1986-90	2
1991-95	2 1/2
1996-2000	3

These estimates are added to the ERDA projection resulting in Curve B + C for all wastes. Thus, curves A, B + C represent high and low estimates of waste generation.

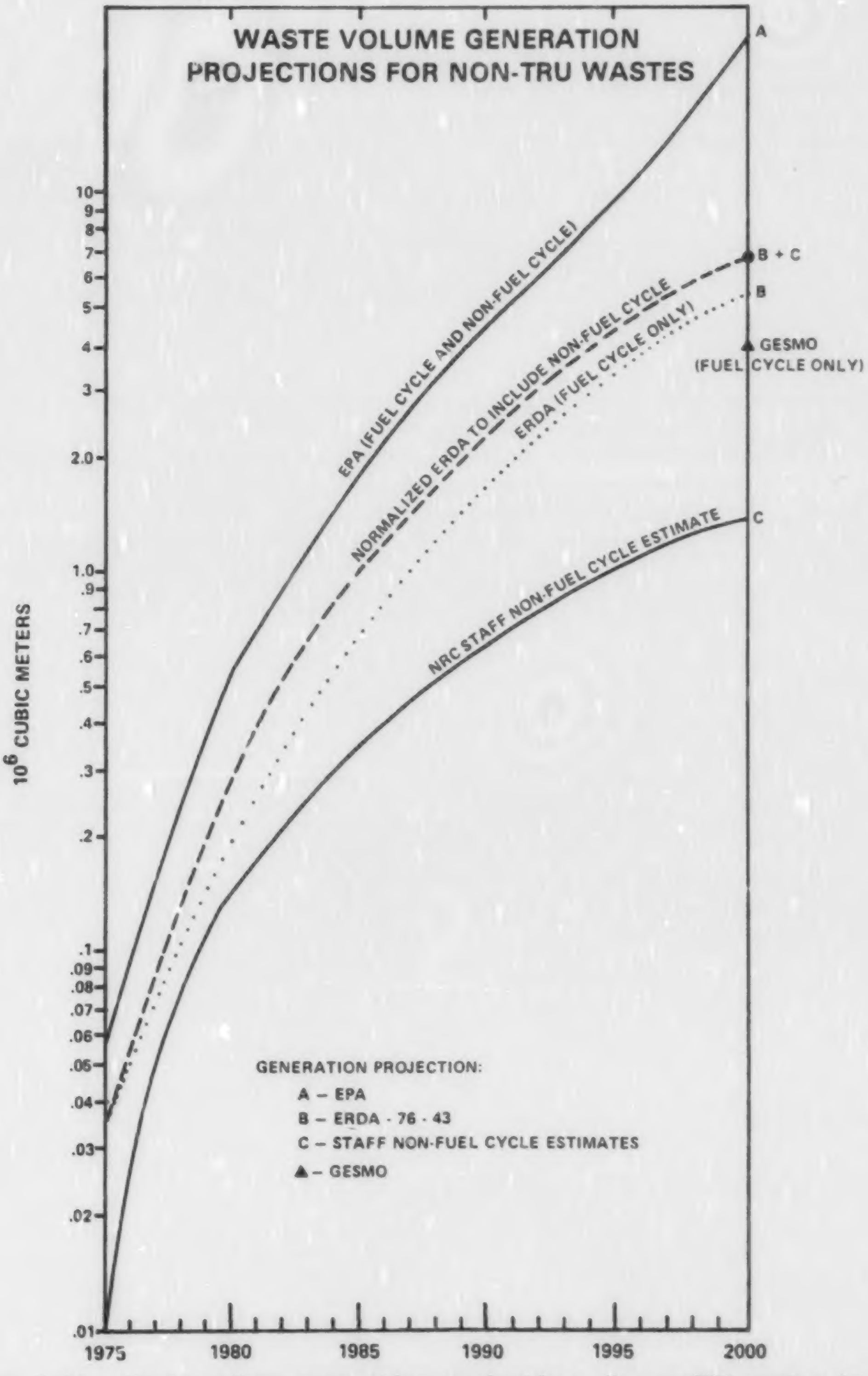


Figure 5-13. Waste volume generation projections for nonTRU wastes *(5.77)*

Estimates of remaining capacities of existing commercial burial grounds are based on NRC discussions with State officials and site operators. If all sites are utilized, the remaining capacity is 6.4 x 10^6 cubic meters (the effects of expansion at the Sheffield site are also shown) (E on figure 5-14). The capacities of unused remaining space at Washington, Nevada, and South Carolina sites are shown as D. As discussed previously the future of Kentucky and New York are uncertain (this capacity is estimated at 3.9 x 10^6 cubic meters) *(5.77)*.

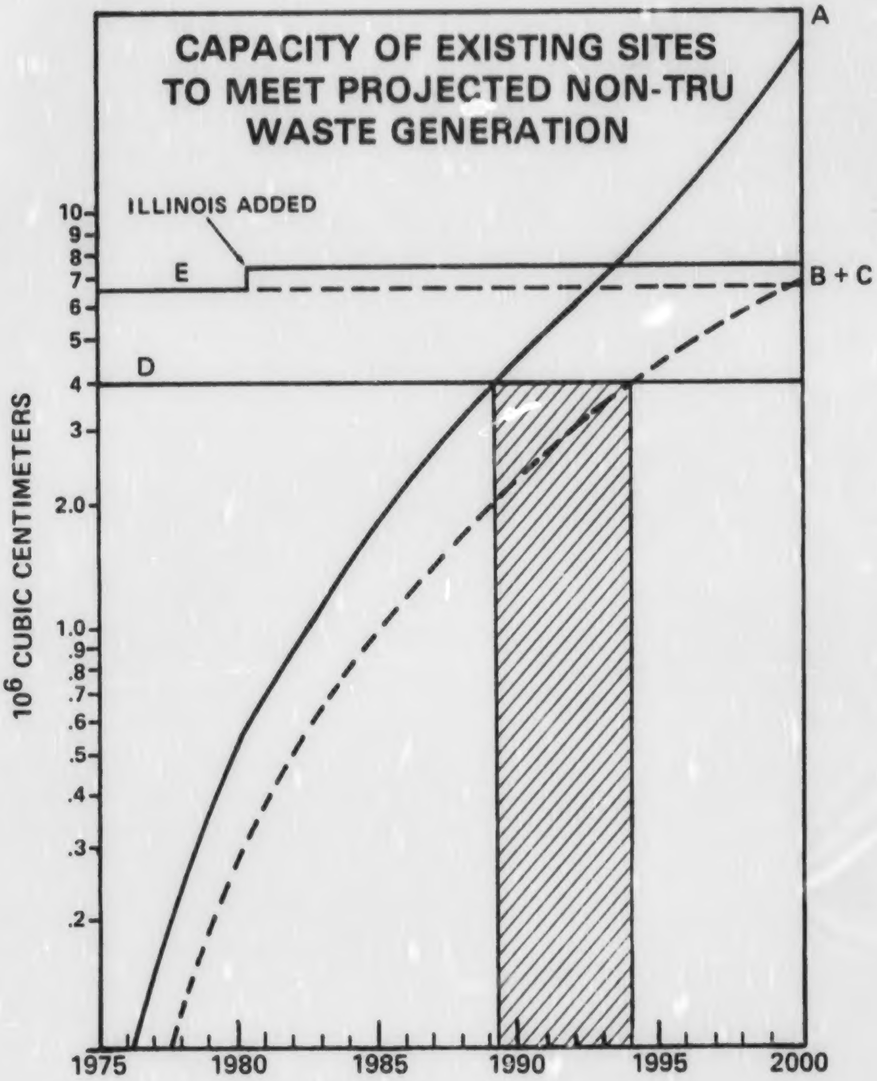
Surveillance information

The site operator conducts an environmental surveillance program in accordance with State or Federal requirements. The program includes sampling of air, water, soil, vegetation, and animals, both on and offsite, to determine whether radioactive material has migrated from the burial location.

Radioactive contamination has been detected migrating from the disposal site to the environment at the Maxey Flats and West Valley facilities. Specific radionuclides, detected in leachates in the trenches and free to migrate to the offsite environment, included: ^{3}H, ^{22}Na, ^{54}Mn, ^{55}Fe, ^{57}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{125}I, ^{129}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{226}Ra, ^{228}Ac, ^{229}Th, ^{232}Th, ^{234}U, ^{235}U, ^{236}U, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am. Little is known at this time about the physical and chemical characteristics of the wastes or of the radioactive contaminants being leached from them. A striking similarity has been noticed, however, between the leachates at Maxey Flats and West Valley and the leachates found at sanitary landfills. Both appear to have a high dissolved solids content (~500,000 ppm) and significant amounts of organic and inorganic acids.

Population doses

There is no information on potential doses to individuals or the general population from low-level waste burial practices. However, two of the commercial burial sites, the West Valley and Maxey Flats disposal facilities, have failed to perform as planned. Authorization to operate the burial facilities was based on analyses of the site hydrology, meteorology, etc., which, it was believed, demonstrated that the buried radioactive wastes would not migrate from the site. That is, they would be retained on the site for hundreds of years. In 10 years or less, radioactivity has been detected offsite.



CAPACITIES:
D: WASHINGTON, NEVADA, S. C. SITES
E: WASHINGTON, NEVADA, S. C., KENTUCKY, N. Y. SITES
PROJECTIONS (FROM FIGURE D-1):
A: EPA
B + C: NORMALIZED ERDA

Figure 5-14. Capacity of existing sites to meet projected nonTRU waste generation *(5.77)*

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Chapter 6 - Federal Facilities

There are two groups of federal facilities that handle radioactive materials and publish reports of their monitoring activities. These groups are those facilities that are operated for the Energy Research and Development Administration and the Navy's nuclear fleet and their support facilities.

ERDA facilities

There are 26 facilities that report their environmental surveillance results to the Energy Research and Development Administration (ERDA) *(6.1-6.2)*. The operators of these facilities are contractors for ERDA and operate facilities that have a potential for environmental impact or may release a significant quantity of radioactive or nonradioactive wastes. In accordance with the ERDA Manual Chapter 0513, these contractors prepare annual reports containing data on levels of radioactive and nonradioactive pollutants in the environs of each site and an interpretation of the sampling results in relation to the appropriate standards for environmental protection. These reports may also include estimates of offsite exposures and summaries of effluent releases that may be necessary to aid in calculations of any offsite exposures *(6.1-6.2)*.

Many of the monitoring reports submitted to ERDA by their contractors contained an assessment of the radiation exposure of the public which could have resulted from site operations during the past calendar year. Each of these assessments provided an estimate of (a) the "fence-post" dose at the location of the site boundary where the maximum exposure rate exists, (b) the dose to an individual and population group in those locations where the highest dose rate occurs, and/or (c) the 80-kilometer (50-mile) person-rem whole body dose. The latter dose is the dose received by the population within an 80-kilometer radius of the facility.

The annual reports were investigated for two types of doses. The first is the boundary dose or the dose to an individual at the perimeter of the secure area of the contractor facility. Twenty-two of the 30 sites (several of the facilities consist of more than 1 site) reported boundary doses in 1974, and 23 of the 29 sites reported boundary doses in 1975. These doses ranged from a low of 0.11 μrem/y at the Pantex plant to a high of 137 mrem/y at the Lawrence Livermore Laboratory in 1974 and a low of 0.2 μrem/y at the Pantex plant to a high of 258 mrem/y at the Lawrence Livermore Laboratory in 1975.

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In addition to reporting the boundary doses due to the activities of a facility, many facilities also reported a background dose that they measured as part of their monitoring program. These background doses, which are a measure of the ambient radioactivity in the environment around these contractor facilities and are due to naturally-occurring radioactivity and sources other than facility operations, ranged from 66 mrem/y at the Knolls Atomic Power Laboratory's Kesselring Site to 200-250 mrem/y at the Rocky Flats Plant for 1974 and 59 mrem/y at the Lawrence Livermore Laboratory to 165 mrem/y at the National Reactor Testing Station in 1975.

The second dose estimate that some of the contractor facilities reported is the dose to the population within 80 kilometers (50 miles) of the site. The majority of the facilities reporting an 80-kilometer population dose reported these doses in the units of person-rem. However, the Los Alamos Scientific Laboratory and the Stanford Linear Accelerator Center reported doses for radii smaller than 80 kilometers in 1974 and 1975. For those facilities that did report comparable person-rem doses, the doses ranged from 7×10^{-7} person-rem at the Pantex Plant to 157 person-rem at the Argonne National Laboratory in 1974 and from 3×10^{-6} person-rem at the Battelle Columbus Laboratory to 181 person-rem at the Ames Laboratory in 1975.

The dose to an individual or population group at those locations where the highest dose rate occurs was presented by very few facilities and, consequently, was not tabulated. In many cases, this dose corresponded to the dose at the site boundary and, in all instances, was equal to or less than the dose at the site boundary. Consequently, only the doses at the site boundary and the 80-kilometer doses are tabulated in tables 6-1 and 6-2.

Department of Defense

Of the facilities using radioactive materials in the Department of Defense, one that issues a report on its environmental program is the nuclear Navy.

At the end of 1974, the U.S. Navy had 105 nuclear-powered submarines and 6 nuclear-powered surface ships in operation *(6.3)*. These totals were increased to 106 nuclear-powered submarines and 7 nuclear-powered surface ships in 1975 *(6.4)*. Nine shipyards, 11 tenders, and two submarine bases are involved in the construction, maintenance, overhaul, and refueling of these nuclear propulsion plants *(6.3-6.4)*.

The Navy monitoring and radioactivity control program begins with tight surveillance and control of radioactive releases and waste disposal. The radiation monitoring program consists of analyzing harbor water and sediment samples for radioactivity associated with nuclear propulsion plants, monitoring of radiation around the perimeter of support facilities, and monitoring of effluents. The primary radionuclides of concern

Table 6-1. Boundary and 80-km doses around ERDA contractor facilities, 1974 *(6.1)*

Facility name and location	Background doses (mrem/y)	Boundary dose to individual in population due to facility (mrem/y)	Population dose within 80 km radius around facility (person-rem/y)	Population within 80 km of site
Ames Lab. Ames, Iowa	(a)	2.91	56.6	590,500
Argonne National Lab. Argonne, Ill.	100	5.4	157.4	7,757,789
Atomics International Canoga Park, Calif.	(a)	(a)	(a)	(a)
Battelle Columbus Lab. Columbus, Ohio	160	2.7×10^{-3}	1.8×10^{-4} (^{85}Kr)	623,400
Bettis Lab. Pittsburgh, Pa.	89.1	2.3	0.2	2,305,000
Brookhaven National Lab. Upton, N. Y.	79	7.5	7.34	5,093,492
Elk River Reactor[b] Elk River, Minn.	(a)	(a)	(a)	(a)
Feed Materials Production Center, Fernald, Ohio	(a)	9	(a)	(a)
Hanford Site Richland, Wash.	100	.17	1.1	250,000
Knolls Atomic Power Lab.				
Knolls Site Niskayuna, N. Y.	73	(a)	.002	1,140,000
Kesselring Site West Milton, N. Y.	66	(a)	.08	1,030,000
Windsor Site Windsor, Conn.	74	<.05	.001	2,830,000
Lawrence Berkeley Lab. Berkeley, Calif.	70-100	28.3	11.6	(a)
Lawrence Livermore Lab. Livermore, Calif.				
Livermore Site	68	[c]137	[d]2.2	4.3×10^6
Site 300	(a)	(a)	(a)	(a)
Los Alamos Scientific Lab. Los Alamos, N. Mex.	128	9	[e].28	92,000
Mound Lab. Miamisburg, Ohio	114	12.3	56	2,800,000
National Accelerator Lab. Batavia, Ill.	(a)	2	2	8,000,000

Table 6-1. Boundary and 80-km doses around ERDA contractor facilities, 1974 *(6.1)* continued

Facility name and location	Background doses (mrem/y)	Boundary dose to individual in population due to facility (mrem/y)	Population dose within 80 km radius around facility (person-rem/y)	Population within 80 km of site
National Reactor Testing Station Idaho Falls, Idaho	160	1.3	2.2	69,500
Nevada Test Site Mercury, Nev.	83-150	(a)	<0.003	4,300
Oak Ridge Facilities Oak Ridge, Tenn.	100	7.7	10	740,000
Paducah Gaseous Diffusion Plant Paducah, Ky.	(a)	9 to lung	(a)	(a)
Pantex Plant Amarillo, Tex.	(a)	1.1×10^{-4}	7×10^{-7}	235,000
Pinellas Plant St. Petersburg, Fla.	120	.012	.34	1,606,676
Portsmouth Gaseous Diffusion Plant Piketon, Ohio	118.7	.35	1.1×10^{-2}	500,000
Rocky Flats Plant Golden, Colo.	200-250	(a)	<28,182	1,540,000
Sandia Lab. Albuquerque, N. Mex.	150	(a)	<1	380,000
Savannah River Plant Aiken, S. C.	135	.94	155	465,000
Shippingport Atomic Power Sta. Shippingport, Pa.	76.1	3.1	.0006	4,000,000
Stanford Linear Accelerator Stanford, Calif.	100	<20	[f]5.3	[f]2,040

[a] Not reported.
[b] Final report, the Elk River reactor has been dismantled.
[c] None of these data have been corrected for natural background. Neutron dose measurements (using a integrating rem meter) at this location indicate an additional annual dose of approximately 370 mrem.
[d] Radiation dose from LLL radioactive effluents.
[e] Population dose for the 17,000 residents of Los Alamos County.
[f] Population and dose 1 mile from the plant.

Table 6-2. Boundary and 80-km doses around ERDA contractor facilities, 1975 *(6.2)*

Facility name and location	Background doses (mrem/y)	Boundary dose to individual in population due to facility (mrem/y)	Population dose within 80 km radius around facility (person-rem/y)	Population within 80 km of site
Ames Lab. Ames, Iowa	(a)	3.46	180.8	590,000
Argonne National Lab. Argonne, Ill.	100	6.2	163.38	8,118,740
Atomics International Canoga Park, Calif.	100	(a)	(a)	(a)
Battelle Columbus Lab. Columbus, Ohio	160	(a)	3.0×10^{-6}	623,400
Bettis Lab. Pittsburgh, Pa.	100	2.4	.10	2,305,000
Brookhaven National Lab. Upton, N. Y.	81	.068	6.8	5,167,172
Feed Materials Production Center, Fernald, Ohio	(a)	10	(a)	(a)
Hanford Site Richland, Wash.	100	.06	.9	250,000
Knolls Atomic Power Lab.				
Knolls Site Niskayuna, N. Y.	75	34	.013	1,780,000
Kesselring Site West Milton, N. Y.	70	10	.16	1,060,000
Windsor Site Windsor, Conn.	74	15	.007	3,130,000
Lawrence Berkeley Lab. Berkeley, Calif.	70-110	(a)	(a)	4,500,000
Lawrence Livermore Lab. Livermore, Calif.				
Livermore Site	59	^{b}258	(a)	4,276,000
Site 300	(a)	(a)	(a)	(a)
Los Alamos Scientific Lab. Los Alamos, N. Mex.	124	.34	^{c}.42	94,000
Mound Lab. Miamisburg, Ohio	(a)	1.43-Lung ^{238}Pu .572-Bone ^{238}Pu 4.84-Whole body ^{3}H	(a)	^{d}1,081,000
National Accelerator Lab. Batavia, Ill.	(a)	1	1	8,000,000

Table 6-2. Boundary and 80-km doses around ERDA contractor facilities, 1975 *(6.2)* continued

Facility name and location	Background doses (mrem/y)	Boundary dose to individual in population due to facility (mrem/y)	Population dose within 80 km radius around facility (person-rem/y)	Population within 80 km of site
National Reactor Testing Station Idaho Falls, Idaho	165	.67	3.3	94,000
Nevada Test Site Mercury, Nev.	90	(a)	.0022	2,170
Oak Ridge Facilities Oak Ridge, Tenn.	100	8.4	7.4	740,000
Paducah Gaseous Diffusion Plant Paducah, Ky.	125	4-Lung 3-Bone	(a)	(a)
Pantex Plant Amarillo, Tex.	(a)	.0002	4.1×10^{-4}	236,000
Pinellas Plant St. Petersburg, Fla.	120	.008	.28	1,656,425
Portsmouth Gaseous Diffusion Plant Piketon, Ohio	119	1.1	.078	500,000
Rocky Flats Plant Golden, Colo.	116	0.19	13.1	(a)
Sandia Lab. Albuquerque, N. Mex.	150	(a)	<1	(a)
Savannah River Plant Aiken, S. C.	135	0.92	94	465,000
Shippingport Atomic Power Station Shippingport, Pa.	73.5	5.1×10^{-4}	(a)	(a)
Stanford Linear Accelerator Center Stanford, Calif.	100	<20	[e]7.3	[e]2,040

[a] Not reported.
[b] Neutron dose measurements indicate an additional annual dose of approximately 700 mrem.
[c] Population dose for the 17,700 residents of Los Alamos County.
[d] Population within 22-mile radius.
[e] Population and dose 1 mile from the plant.

are cobalt-60 and tritium. The total radioactivity, less tritium, discharged to all ports and harbors from these facilities was less than 0.002 curie in 1974 and 1975. The total tritium released to all ports and harbors was less than one curie in 1974 and 1975. Based on the radioactivity released, the maximum radiation dose to any member of the general public in 1974 and 1975 was less than 0.01 millirem.

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Chapter 7 - Radiopharmaceuticals

Radiopharmaceuticals are used in the diagnosis and, in some cases, the treatment of disease. Their use has increased fivefold from 1960 to 1970, and it has been estimated that an increase of sevenfold may be experienced from 1970 to 1980. If this trend continues, and there are no technical changes, it is estimated that the whole-body dose to the United States population in 1980 from the use of radiopharmaceuticals will be 3.3 million person-rem *(7.1)*.

In June 1976, the Bureau of Radiological Health published a report on a pilot study of nuclear medicine in United States hospitals. This study compares current nuclear medicine data obtained from six hospitals with survey data collected from the same institutions in previous years *(7.2)*. Although these data cannot be considered to be representative of nuclear medicine practice in all U.S. hospitals, the study notes that several trends are apparent.

These trends are:

1. An average increase in nuclear medicine procedures in excess of 17 percent per year.

2. An increase in the average whole body and gonad radiation doses per radiopharmaceutical administration when compared to 1966 national data.

3. A high proportion (21 percent) of nuclear medicine procedures performed on patients under the age of 30.

The contribution of nuclear medicine to the total medical radiation exposures to the population may be greater than previously estimated if the trends indicated in the pilot study are a reflection of the practice of nuclear medicine throughout the United States.

Although radiopharmaceuticals used in diagnosis and treatment of disease result in the major doses to man, additional doses to man result from the manufacture of radiopharmaceuticals and from the discharge of these materials to the environment from patients and medical facilities.

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A search of available literature unfortunately has not revealed any information concerning the release of radiopharmaceuticals to the environment during manufacturing processes, thus, the effect of these materials cannot be determined.

In order to estimate the total contribution to population doses from the discharges of radiopharmaceuticals, each medical facility would require evaluation because of the unique ways each might contribute to the environmental contamination. Thus, it is concluded that little inference can be made at this time about the dose and contamination that results from the discharge from radiopharmaceuticals from patients and medical facilities.

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Chapter 8 - Medical Radiation

The responsibility for controlling medical exposure to radiation is divided between the Federal and the State governments. Within the Federal Government, the Bureau of Radiological Health in the Department of Health, Education and Welfare has the responsibility of administrating the Radiation Control for Health and Safety Act (Public Law 90-602). The Secretary of Health, Education and Welfare is required by the act to submit an annual report to the President for transmittal to the Congress *(8.1)*.

A model State Radiation Control Act containing suggested model regulations for control of radiation was published by the Council of State Governments with the cooperation and assistance of interested Federal Agencies *(8.2)*. This publication assisted the States in making regulations compatible with each other and with the Federal Government. Fifty states, the District of Columbia and the Commonwealth of Puerto Rico now have laws for the regulation of ionizing radiation *(8.3)*.

The use of radiation by the medical profession is recognized as the largest manmade component of radiation dose to the United States population. This includes medical diagnostic radiology, clinical nuclear medicine, radiation therapy, cardiac pacemakers, and occupational exposure of medical and paramedical personnel. However, the main contributor of the total dose from medical exposures is diagnostic x radiation; the contribution from dental radiation, radiopharmaceuticals, and radiation therapy being far lower. Medical diagnostic radiology accounts for at least 90 percent of the total manmade radiation dose to which the U.S. population is exposed. This is at least 35 percent of the total radiation dose from all sources (including natural radioactivity) *(8.4,8.5)*.

Genetically significant dose

The Bureau of Radiological Health (BRH), in cooperation with the National Center for Health Statistics (NCHS), conducted an X-ray Exposure Study (XES) in 1964 and another in 1970. A dose model was developed for use in calculating the gonad dose from the XES data and a report was published in April 1976 illustrating changes in gonad and genetically significant dose (GSD) from diagnostic x-ray procedures between 1964 and 1970 *(8.6)*. However, the report considers only medical radiographic examinations and the radiographic portions of fluoroscopy. Dental x-ray examinations and doses from therapy were not included.

Ten statistically significant changes in mean gonad dose per examination from 1964 to 1970 were observed (table 8-1). The largest increase occurred for barium enema examinations of females (578 mrad to 903 mrad) and the largest decrease occurred for intravenous or retrograde pyelogram examinations of males (537 mrad to 207 mrad).

Examination types which involve the abdomen result in high mean gonad doses while those examination types which involve the head, neck, thorax and extremities generally result in low mean gonad doses (table 8-1). Therefore, eight examination types produced over 90 percent of the GSD in 1964 and in 1970 (table 8-2). Theoretically, restriction of the beam size to the film size would have reduced the 1964 GSD by 33 percent and the 1970 GSD by 21 percent. The change in the estimate of the GSD from 17 millirads in 1964 to 20 millirads in 1970 was not statistically significant *(8.6)*. This report notes that recent evaluations indicate that genetic effects should not be considered the primary hazard of radiation and that increasing emphasis is being placed on the somatic effects of radiation *(8.6)*.

Somatic dose

In January of 1977, BRH published a report presenting estimates of the mean active bone marrow doses to adults resulting from x-ray exposure during radiographic, fluoroscopic, and dental examinations. The report analyzes data from the 1970 X-Ray Exposure Study and estimates that medical radiographic procedures contributed approximately 77 percent of the total mean active bone marrow dose to adults from diagnostic radiology, while fluoroscopic and dental examinations contributed about 20 percent and 3 percent, respectively. Examinations of the upper and lower abdomen contributed approximately 78 percent of the dose to adults, followed by 12 percent from the thorax, 6 percent from the head and neck (including dental examinations), and 4 percent from pelvic examinations (table 8-3).

The major contributors to the mean active bone marrow dose in the 15-34 year old group are x-ray examinations of the lumbar spine and lumbosacral spine. After age 45, the highest contributors were the upper GI series and barium enema examinations *(8.7)*. The estimated mean active bone marrow doses for children were not included because the data were not available.

The estimated annual per capita mean active bone marrow dose to U.S. adults from diagnostic radiology procedures in 1970 was 103 millirads, compared to 83 millirads in 1964 showing an increase of 23 percent (tables 8-3, 8-4). This increase probably resulted from an increase in the doses associated with radiographic procedures and not from an increase in examination rates. The increased dose is attributed to an increased exposure per film *(8.7)*.

Another estimation of somatic dose was presented by EPA in 1972 *(8.4)*. They estimated that the annual abdominal dose to an individual in the U.S. population from medical and dental radiation was 72 mrem in 1970. This results in a population dose of 14.8 million person-rem for 1970 *(8.8)*.

Table 8-1. Estimated mean gonad dose per examination by type of radiographic examination and sex, United States, 1964 and 1970 *(8.6)*

	Mean gonad dose (mrad)							
	Male				Female			
	1964		1970		1964		1970	
Type of examination	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Skull	-	-	-	-	-	-	-	-
Cervical spine	-	-	-	-	-	-	-	-
Chest								
Radiographic	1	-	-	-	5	1	* 1	-
Photofluorographic	-[a]	-	2[a]	2	5[a]	1	3[a]	-
Thoracic spine	46	55	3	3	17	8	11	2
Shoulder	-	-	-	-	-	-	-	-
Upper gastrointestinal series	22	11	1	1	128	19	*171	15
Barium enema	133	46	175	70	578	63	*903	111
Cholecystography or cholangiogram	-	-	-	-	72	15	78	17
Intravenous or retrograde pyelogram	537	172	*207	66	437	43	*588	47
Abdomen, KUB, flat plate	63	21	97	42	248	41	221	25
Lumbar spine	108	39	218	98	520	65	*721	50
Pelvis	444	101	364	76	130	19	*210	34
Hip	718	244	600	135	196	31	*124	15
Upper extremities	-	-	-	-	1	1	-	-
Lower extremities	38	11	* 15	7	-	-	-	-
Other abdominal exams	331	178	857	332	256	48	*524	84
All other	1	1	-	-	4	2	6	4

S.E. = Standard error
* = change in mean gonad dose from 1964 to 1970 was statistically significant ($P < 0.10$)
- = less than 0.5 millirads
a = These figures are based upon assigned values of exposure, free-in-air at tabletop, because of the lack of specific exposure measurements.

Table 8-2. Estimated annual genetically significant dose contributions by type of radiographic examination and sex, United States, 1964 and 1970 *(8.6)*

Type of examination	Genetically significant dose (mrad)											
	Male						Female					
	N.	1964 GSD cont.	S.E.	N.	1970 GSD cont.	S.E.	N.	1964 GSD cont.	S.E.	N.	1970 GSD cont.	S.E.
Skull	39	-	-	112	-	-	39	-	-	88	-	-
Cervical spine	26	-	-	80	-	-	44	-	-	83	-	-
Chest												
Radiographic	384	0.1	0.1	772	-	-	386	0.3	0.1	807	0.1	-
Photofluorographic	226	-	-	118	0.1	0.1	260	0.2	0.1	155	-	-
Thoracic spine	17	0.3	0.7	38	-	-	16	-	0.1	46	-	-
Shoulder	17	-	-	48	-	-	26	-	-	56	-	-
Upper gastrointestinal series	71	0.1	0.1	142	-	-	77	0.4	0.4	170	0.4	0.2
Barium enema	32	0.4	0.7	76	0.3	1.4	46	2.2	1.4	98	1.7	1.4
Cholecystography or cholangiogram	29	-	-	65	-	-	50	0.1	0.2	118	0.6	0.5
Intravenous or retrograde pyelogram	46	1.3	4.0	93	1.0	0.9	37	1.4	1.4	99	2.2	1.0
Abdomen, KUB, flat plate	54	0.4	0.4	72	0.4	0.2	30	0.4	0.7	85	1.1	0.5
Lumbar spine	55	0.8	0.7	147	0.5	0.2	51	1.7	1.3	130	3.1	1.2
Pelvis	32	2.4	3.0	28	0.7	0.7	27	0.1	0.4	58	1.1	0.5
Hip	13	0.5	1.6	18	0.7	0.7	20	0.1	0.7	51	0.2	0.1
Upper extremities	114	-	-	231	-	-	77	-	-	205	-	-
Lower extremities	176	1.4	0.7	298	0.6	0.4	106	-	-	281	-	-
Other abdominal exams	13	0.7	1.6	29	0.8	1.2	16	0.4	0.8	59	*3.0	1.2
All other	46	-	-	114	-	-	36	-	-	100	-	-

N = number of cases in sample
- = less than 0.05 millirads
S.E. = Standard error
GSD cont. = GSD contribution
* = change in GSD contribution from 1964 to 1970 was statistically significant ($P < 0.10$)

Table 8-3. Mean active bone marrow dose to the adult population (1970) *(8.7)*

Examination	Mean active bone marrow dose per examination (mrad)	Annual per capita examination rate	Annual per capita dose (mrad ± S.E.)	
Head and neck				
Skull	78	0.020		1.6 ± 0.1
Cervical spine	52	0.022		1.2 ± 0.2
Other	--	---		0.6 ± 0.2
Thorax				
Chest-photofluoro.	44	0.073		3.2 ± 0.3
Chest-radiographic	10	0.306		3.2 ± 0.1
Thoracic spine	247	0.010		2.5 ± 0.4
Ribs	143	0.009		1.3 ± 0.2
Other	--	---		1.9 ± 0.4
Upper abdomen				
Upper GI series (total)	535			24.3 ± 4.7
Radiographic (subtotal)	294	0.046	13.5 ± 4.3	
Fluoroscopic (subtotal)	241	0.045	10.8 ± 1.9	
Scan	167			
Spot films	74			
Lumbar spine	347	0.023		8.1 ± 0.8
Gall bladder (total)	168			3.7 ± 0.4
Radiographic (subtotal)	129	0.027	3.5 ± 0.3	
Fluoroscopic (subtotal)	39	0.006	0.2 ± 0.3	
Scan	29			
Spot films	10			
Small bowel series	422	0.002		1.0 ± 0.3
Other				2.1 ± 1.0
Lower abdomen				
Barium enema (total)	875			21.2 ± 1.8
Radiographic (subtotal)	497	0.024	11.9 ± 1.0	
Fluoroscopic (subtotal)	378	0.024	9.3 ± 1.5	
Scan	268			
Spot films	110			
IVP	420	0.024		10.1 ± 0.6
Lumbosacral spine	450	0.013		5.7 ± 0.7
Abdomen KUB	147	0.020		2.9 ± 0.4
Other	--	---		0.4 ± 0.2
Pelvis				
Pelvimetry	595	0.002		1.4 ± 0.5
Pelvis	93	0.012		1.1 ± 0.2
Hip	72	0.009		0.7 ± 0.1
Other	--	---		1.2 ± 0.7
Extremities				
Femur	21	0.002		0.04 ± 0.02
Dental	9.4	0.312		2.9 ± 0.2
			Total	103 ± 5

Table 8-4. Mean active bone marrow dose to the adult population (1964) *(8.7)*

Examination	Mean active bone marrow dose per examination (mrad)	Annual per capita examination rate	Annual per capita dose (mrad ± S.E.)	
Head and neck				
Skull	65	0.016		1.0 ± 0.2
Cervical spine	31	0.018		0.6 ± 0.1
Other	--	---		0.6 ± 0.2
Thorax				
Chest-photofluoro.	65	0.120		7.8 ± 0.9
Chest-radiographic	10	0.219		2.0 ± 0.3
Thoracic spine	232	0.009		2.0 ± 1.0
Ribs	124	0.006		0.7 ± 0.3
Other	--	---		0.5 ± 0.2
Upper abdomen				
Upper GI series (total)	408			17.9 ± 1.6
Radiographic (subtotal)	229	0.042	9.7 ± 1.0	
Fluoroscopic (subtotal)	195	0.042	8.2 ± 1.3	
Scan	161			
Spot films	34			
Lumbar spine	336	0.020		6.7 ± 1.4
Gall bladder (total)	183			3.2 ± 0.4
Radiographic (subtotal)	146	0.021	3.1 ± 0.5	
Fluoroscopic (subtotal)	27	0.002	0.1 ± 0.2	
Scan	24			
Spot films	2.5			
Small bowel series	271	0.003		0.7 ± 0.3
Other				1.0 ± 0.6
Lower abdomen				
Barium enema (total)	624			13.7 ± 1.6
Radiographic (subtotal)	351	0.022	7.7 ± 1.3	
Fluoroscopic (subtotal)	273	0.022	6.0 ± 0.9	
Scan	229			
Spot films	44			
IVP	453	0.022		9.9 ± 1.2
Lumbosacral spine	418	0.010		4.0 ± 1.0
Abdomen KUB	183	0.020		3.6 ± 0.9
Other	--	---		0.3 ± 0.4
Pelvis				
Pelvimetry	288	0.001		0.3 ± 0.5
Pelvis	116	0.012		1.4 ± 0.5
Hip	97	0.008		0.7 ± 0.4
Other	--	---		1.2 ± 0.7
Extremeties				
Femur	--	---		---
Dental	13.2	0.267		3.5 ± 0.2
			Total	83 ± 4

Cardiac pacemakers

In the United States, heart disease is now the leading killer. However, thousands of men and women are alive today because of artificial cardiac pacemakers which use electricity to help the heart operate.

Cardiac pacemakers control heart rhythm by delivering electrical impulses to the muscles of the heart causing their contraction. These devices are implanted in patients suffering from certain forms of abnormal heart rhythms. The conventional pacemakers powered by mercury batteries last from 2 to 3 years and require surgical replacement of the entire pacemaker when the battery power is no longer sufficient. However, since 1972, cardiac pacemakers powered by nuclear batteries containing plutonium-238 have been implanted in hundreds of patients in the United States on a limited investigational basis. These nuclear batteries have a life span of over 10 years *(8.8)*.

In July 1976, the Nuclear Regulatory Commission's Office of Nuclear Material Safety and Safeguards issued a Final Generic Environmental Statement on the routine use of plutonium-powered cardiac pacemakers. The statement concludes that the benefits to the patient outweigh the risks involved, therefore, plutonium-powered pacemakers can be licensed for routine use. Prior to this, the Commission had licensed plutonium-powered pacemakers on a limited investigational basis *(8.8)*.

Total critical organ and whole body doses received by pacemaker patients are less than 5 rem/year while exposure to families and others in the population involves a dose equivalent to individual spouses of up to 7.5 millirems per year and to individual nonfamily associates of up to 0.2 millirem per year (table 8-5) *(8.8)*.

The Nuclear Regulatory Commission proposed a general license for routine use of plutonium-238 powered cardiac pacemakers in the Federal Register on March 14, 1977.

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Table 8-5. Radiation doses to critical groups from cardiac pacemakers (assuming 10,000 implanted cardiac pacemakers with plutonium batteries)(8,8)

		Individual dose (mrem/person/year)			Total dose to group	
			Average dose		(Person-rem/year)	
Relationship to pacemaker patients	Group population	Dose from pacemaker[a]	Medical x rays	Natural background radiation	Dose from pacemaker[b]	Natural background radiation
Spouses	6,430	5-7.5	73	102	42	646
Household members	8,950	1-1.5	73	102	12	912
Work associates[c]	72,000	0.1-0.2	73	102	10.5	7,344
Nonwork associates[c]	218,000	0.05-0.1	73	102	14.5	22,378
Total in U.S. populace not included above		<<0.01	73	102	49	21,400,000
Total dose to U.S. population excluding dose to patients[d]					128	

[a] Dose will vary depending upon the plutonium content, fuel characteristics, and shielding effects of a particular pacemaker model.

[b] Integrated dose using 4 Ci of plutonium which is the average amount of plutonium used in any battery.

[c] A patient is predicted to associate with about 30 persons during his daily activities.

[d] U.S. population of 210,000,000.

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Chapter 9 - Occupational and Industrial Radiation

There is surprisingly little data published in the scientific literature on the contributions of occupational exposure to the population dose from ionizing radiation. However, there is a large quantity of data available in various dosimetry programs throughout the United States *(9.1,9.2)*. In general, personnel monitoring programs are designed to check that exposures of radiation workers do not exceed some specified level. In addition, it is usual to ignore doses below a minimum detectable level or below the "investigation level" set for monitoring purposes.

The Federal Radiation Council in May 1960 recommended Radiation Protection Guides for the use by Federal agencies in their radiation protection activities *(9.3)*. These guides (table 9-1) are being reviewed by the Environmental Protection Agency, and it is anticipated that EPA will formally submit updated guidance to the President for approval sometime in 1978.

Close adherence to the FRC guides and the recommendations of such bodies as the International Commission on Radiological Protection, the International Labour Organization, the World Health Organization, and the International Atomic Energy Agency insures that most workers receive very low exposures and that very few workers exceed the recommended maximum permissible doses. The maximum permissible annual dose to the whole body is about 50 times that received from natural radiation sources. In 1970, the total per capita dose from occupational exposures to radiation was estimated as 0.8 mrem/y, with a mean dose per worker of 200 mrem/y *(9.4)*.

One of the problems encountered in dealing with occupational radiation is in defining "radiation worker." It can mean all of the staff in certain establishments, or in other work places, only those personnel whose exposures might exceed three-tenths of the annual dose limit. In 1966 the ICRP introduced the concept of a single category of occupational exposure, the radiation exposure received by any worker in the course of his work, with the recommendations that only those workers whose doses might exceed three-tenths of the annual maximum permissible dose require individual personal monitoring and health supervision. But in practice, this recommendation has not been carried out, and the majority of persons issued personal monitoring devices still record annual doses less than three-tenths of the maximum permissible doses.

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Table 9-1. Radiation protection guides *(9.3)*

Type of exposure	Condition	Dose (rem)
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye	Accumulated dose	5 times the number of years beyond age 18.
	13 weeks	3.
(b) Skin of whole body and thyroid	Year	30.
	13 weeks	10.
(c) Hands and forearms, feet and ankles	Year	75.
	13 weeks	25.
(d) Bone	Body burden	0.1 microgram of radium-226 or its biological equivalent.
(e) Other organs	Year	15.
	13 weeks	5.
Population:		
(a) Individual	Year	0.5 (whole body).
(b) Average	30 year	5 (gonads).

The UN Scientific Committee reported that a representative figure for the number of radiation workers for most developed countries is 1-2 workers per thousand population, with the U.S. 1970 figure being somewhat higher. The UN data for the United States reports 1.33/thousand workers engaged in medical work, 0.87 in dental, 1.55 in research and education, with a total of 3.7/thousand *(9.2)*. There are no data reported in categories termed atomic energy and industrial, and it is not clear whether the medical category includes diagnosis, therapy, chiropractic, or veterinary. Klement et al. reported 3.76 radiation workers in the United States by "using reported numbers of workers and judicious estimates in nonreported areas" *(9.1)*.

There is no requirement for uniformity in collecting and reporting occupational exposures. There are considerable variations in the terminology used by reporting agencies. For example, results of personnel monitoring data are reported as exposures (R), absorbed doses (rad) or dose equivalents (rem). The dose equivalent is used frequently because this is the term used by the International Commission on Radiological Protection (ICRP) to express the maximum permissible doses for occupational exposure and by the Federal Radiation Council for radiation protection guidance for federal agencies.

With external monitoring, there is generally little data available about the actual doses received by the various tissues; workers generally wear one dosimeter--doses to those parts distant from the monitoring device will generally be lower. The value reported is assumed to be the value of the device (recorded dose). "For various reasons, therefore, it is probable that the direct use of data about individual doses from personnel monitoring programmes will tend to overestimate population doses for the various tissues of interest, but at the low levels currently involved, this is not considered to be a serious problem." *(9.2)*.

Data on licensed installations in the United States in 1968 reported in a UN report indicate that in general the great majority of exposures reported through film badge monitoring of a sample of workers using radioactive materials are in the lower dose ranges. However, the data indicate a large percentage of waste disposal workers with exposures in high dose ranges, and this was also true to a lesser extent of industrial radiographers *(9.2)*.

A survey carried out during the period 1965-1970 by the United Kingdom showed that the radiation doses received by site radiographers were significantly higher than those of radiographers in factories. The survey was of radiographers employed by firms who use ionizing radiation in nondestructive testing. The reasons are probably complex; the type of equipment used and the standard of protection provided for the operation are important controlling elements *(9.5)*.

Accidents and overexposures are rare in most types of radiation work today. However, there are some exceptions--most reported radiation injuries occur in industrial radiography and users of x-ray crystallographic machines. There is a problem in reducing the inhalation exposures of miners (particularly in underground uranium mining) which is the major casual factor for the excess of respiratory cancers among uranium miners as a group *(9.6)*.

Extensive use of radium in medicine and industry began in the United States in 1913 and the highest occupational exposure to workers occurred before 1925 when the toxic effects of radium became known and safety measures were adopted. Up to about 1930, other persons acquired significant burdens through deliberate intake of radium for supposed therapeutic effects. A revival of the radium dial industry during World War II led to the exposure of another large group of people with significant levels of internally deposited radioactivity.

The Radium Project Registry, which registers all authenticated cases of radium exposure, is maintained at the Center for Human Radiobiology at Argonne National Laboratory. From the records of earlier radium projects and from search efforts since the Center was formed in 1969, approximately 5,000 persons have been identified by name and by type of exposure to radium. Annual reports are published by the Center each year which include papers and reports dealing with different aspects of the Center's studies of the effects of internally deposited radionuclides in humans as well as exposure data for persons whose body burdens of radium have been measured. Another major project of the Center is a study of the health of former thorium workers. The study involves analysis of mortality and morbidity in former workers in a company concerned with the production of thorium (and rare earth) chemicals *(9.7-9.9)*.

There has been some difficulty in the luminizing industry in preventing excessive uptake of tritium by the workers. Tritium and, to some extent, promethium have replaced radium as the light activator in phosphors. In general, the occupational exposure to radium is higher than to tritium (and radium offers little advantage as compared to tritium). The occupational exposure to promethium-147 cannot be measured with any degree of accuracy--no data are available and none can be expected to be available because of the extreme difficulties in measuring the body burden of the workers. The chemical properties of radium and promethium are similar. Table 9-2 summarizes risks from processing 1 curie of radium, promethium-147 and tritium. Table 9-3 contains average occupational exposure to tritium as measured by Moghissi et al. and Krejci *(9.10)*.

In a study sponsored by two flight attendants' unions and NRC, radiation doses received by flight attendants from shipments of radioactive materials transported on commercial airline flights in the United

Table 9-2. Total risk from various radionuclides per curie processed *(9.7)*

Occupation	Risk per Ci processed (person-mrem)		
	Radium	Tritium	Promethium-147
Dial Painting			
Bone	200,000	NA	Unknown
Whole body	600,000	9.1	5*
Lung	125,000	NA	Unknown
Assembly			
Whole body	69,000	4.5*	Unknown
Storage			
Whole body	Unknown	12*	Unknown
Environmental (user's dose from wristwatches)			
Whole body	$(65-70)10^6$	30	5000

*Estimated values with limited usefulness

Table 9-3. Average occupational exposure to tritium according to Moghissi, et al. *(9.7)*

Location of plants	Average activity in paint (mCi/g)	Processed tritium (Ci/person-y)	Average urine activity (μCi/l)	Risk (person-mrem/Ci)	Reference
U.S.A.	150	104.3	20.4	19.1	Moghissi et al.
Switzerland	150	193.4	2.57	1.3	Krejci
Switzerland	227	64.9	3.43	5.3	Krejci
Switzerland	102	140.8	7.64	5.4	Krejci
Switzerland	164	222.2	13.1	5.9	Krejci
Switzerland	262	67.6	4.86	7.2	Krejci
Switzerland	354	79.6	9.57	12.0	Krejci
Switzerland	453	65.3	14.2	21.7	Krejci
Average				9.1	

States were measured in late 1974 using thermoluminescent dosimeters (TLD) to measure the exposure. Flight attendants spend as much as 1,000 hours per year on board aircraft in relative close proximity to the cargo department. The study, however, has limited value because of many aspects such as reliance on volunteer cooperation of attendants, inability to always determine the transport indices of packages of radioactive materials on the flight, inability to determine the geometric relationship of the flight attendant to the radioactive cargo, differences between the control and body badges, etc. Nevertheless, analyses of the data indicate that there is little increase in the radiation dose received by flight attendants from shipments of radioactive material; the average increase in dose to participating flight attendants was estimated to be about 11 millirems per year. The maximum increase in dose to any individual flight attendant is unlikely to exceed 140 millirems per year. According to the same report, individuals in the United States receive an average annual dose of about 100 millirems from natural background radiation sources *(9.11)*.

A program for the reporting of certain occupational radiation exposure information on monitored individuals to a central repository was approved by the AEC in 1968 and arrangements were made for the establishment of a central, computerized repository at the Union Carbide Computing Technology Center, Oak Ridge, Tenn. Information was required from four categories of AEC licensees (operating nuclear power facilities; industrial radiographers; fuel processors and distributors of specified quantities of byproduct materials) and from AEC contractors exempt from licensing (Part 20.407 and Part 20.408 of Title 10, Chapter 1, Code of Federal Regulations). Certain information obtained from personnel overexposure reports submitted by all licensees and contractors would also be maintained in the repository (10 CFR 20.403, 10 CFR 20.405, and AEC Manual Chapter 0502).

With the division of the AEC into the two agencies, the Energy Research and Development Administration (ERDA) and the U.S. Nuclear Regulatory Commission (NRC), in January 1975, each of the agencies assumed responsibility for collecting occupational radiation exposure information relating to its own activities. Both ERDA and NRC have continued to retain similar data and computer systems at the Union Carbide Computing Technology Center at Oak Ridge.

In 1974, 10 CFR 20.407 was amended to require covered licensees to submit an annual statistical summary of exposures and data rather than identification and exposure data for individuals whose annual exposure exceeded applicable quarterly limits. The new reporting system was adopted to give a much better indication of the actual distribution of whole body exposures.

A summary of the distribution of annual whole body exposures of some 78,713 individuals reported by 387 NRC-covered licensees for 1975 is given in table 9-4. The average exposure per individual based on all exposures was 0.36 rem (table 9-5). The figures reported in these tables are based on radiation exposures as determined by various types of personnel monitoring devices. Very few of the annual exposures that exceed 5 rems are personnel overexposures because licensees are permitted, under certain conditions, to allow a worker to receive a whole body dose of 3 rems per calendar quarter (or 12 rems annually) *(9.12)*. Annual exposures that exceed 12 rems are overexposures.

The Office of Standards Development of NRC is currently developing a proposed amendment to 10 CFR Part 20 of NRC regulations to require licensees to use personnel dosimetry whose performance has been tested and found to be reasonably accurate. The proposed amendment would apply to film badges and thermoluminescence dosimeters--dosimeters that are processed by the licensee himself or processed commercially for the licensee. It is anticipated that the proposed rule will be published in July 1977 *(9.13,9.14)*.

Sections 20.403 and 20.405 of Title 10, Chapter 1, Code of Federal Regulations, require all licensees to report personnel exposures in excess of applicable limits to the central repository at Oak Ridge. Table 9-6 summarizes the personnel overexposures to external sources of radiation reported by NRC licensees for the years 1971 through 1975. The types of licensees included in the category labeled "other" consist primarily of test reactors and research and educational facilities. Personnel exposures to excessive concentrations (usually airborne) of radioactive materials are summarized in table 9-7 *(9.12)*.

Data from NRC on occupational radiation exposure at light-water-cooled power reactors is presented in table 9-8. This table represents an updating of the information contained in WASH-1311 and NUREG-75/032 which provided data through 1974. Data on those plants operating during the period 1969-1973 were obtained by direct inquiry to the reactor licensee. The 1974-1975 data were obtained from two sources: 1) annual statistical summary of exposure and data reports submitted to NRC to meet the requirements of 10 CFR Part 20.407, and 2) annual, semiannual or monthly operating reports submitted in accordance with individual station Technical Specification *(9.15)*.

The term person-rem used by NRC is a unit of collective dose and is the accumulation of the occupational radiation exposures of all individuals at the plant site including utility station personnel, temporary utility personnel, contractor personnel and visitors. NRC determined this accumulation of exposure by either of two methods:

1. Approximately one-half of the licensees submitted the summation of the actual exposures of all the individuals at their site.

2. For the remaining licensees the accumulated exposures were determined by summing the product of the numbers of individuals in each annual exposure range specified in 10 CFR Part 20.407 b(2) by the mid-point exposure in each range.

Table 9-4. Distribution of annual whole body dose equivalents reported by NRC-covered licensees-1975 *(9.12)*

Covered Categories of NRC Licensees	Total No. Monitored	Exposure Ranges (Rem)																	
		Less than Measurable	Meas'ble <0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.75 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	> -12
Power Reactors	54763	26729	10606	4081	2948	1778	1384	3982	1873	692	424	169	60	24	12	0	1	0	0
Industrial Radiography	9178	4485	1811	813	614	346	263	538	171	54	35	21	8	1	3	1	2	1	1
Fuel Processing & Fabrication	11405	5910	1968	1102	1021	433	241	381	153	77	40	30	11	9	14	15	0	0	0
Manufacturing & Distribution	3367	1508	644	532	214	88	67	140	65	43	39	11	12	3	0	1	0	0	0
Totals	78713	38632	15029	6528	4797	2645	1955	5041	2262	876	538	231	91	37	29	17	3	1	1

Table 9-5. Whole body dose accumulated by categories of NRC-covered licensees, 1975 *(9.12)*

Covered Categories of NRC Licensees	Calendar Year	Number of Licensees Per Category	Total No. Individuals Monitored	No. Individuals With Measurable Exposure	Total No. person-rem	Average Dose Equivalent Per Individual (rem)(Based on all exposures)	Average Dose Equivalent Per Individual (rem)(Based on measurable exposures)
Commercial Power Reactors	1975	54	54,763	28,034	21,270	0.39	0.76
	1974	53	62,044	21,904	14,083	0.23	0.64
	1973	41	44,795	16,558	14,337	0.32	0.87
Industrial Radiography	1975	291	9,178	4,693	2,796	0.30	0.60
	1974	319	8,792	4,943	2,938	0.33	0.59
	1973	341	8,206	5,328	3,354	0.41	0.63
Fuel Processing and Fabrication	1975	23	11,405	5,495	3,125	0.27	0.56
	1974	25	10,921	4,617	2,739	0.25	0.59
	1973	27	10,610	5,056	2,400	0.23	0.47
Processing and Distribution of Byproduct Material	1975	19	3,367	1,859	1,188	0.35	0.63
	1974	24	3,340	1,827	1,050	0.31	0.57
	1973	34	4,251	1,925	1,177	0.28	0.61
Totals and Overall Averages	1975	387	78,713	40,081	28,379	0.36	0.71
	1974	421	85,097	33,291	20,810	0.24	0.63
	1973	443	67,862	28,867	21,268	0.31	0.74

Table 9-6. Summary of overexposures to external sources of radiation reported by NRC licensees *(9.12)*

Calendar Year	Part of Body	Total No. of Overexposures	Total of Doses in Rems	No. of Overexposures and (Sum of the Doses in Rems) Per Licensed Activity: Industrial Radiography	Power Reactors	Manufacturing & Distribution	Medical	Other
1971	Whole Body	43	189.7	20 (99.2 rems)	2 (4.5 rems)	5 (21.4 rems)	13 (58.4 rems)	3 (6.2 rems)
	Skin	2	22.1	--	--	--	--	2 (22.1 rems)
	Extremity	13	4,681	5 (4,444 rems)	--	5 (135 rems)	--	3 (102 rems)
1972	Whole Body	47	466.8	18 (372.3 rems)	16 (49.7 rems)	3 (6.3 rems)	--	10 (38.5 rems)
	Skin	1	40.1	--	--	--	--	1 (40.1 rems)
	Extremity	12	10,760	4 (10,516 rems)	--	6 (134 rems)	--	2 (110 rems
1973	Whole Body	58	210.3	23 (101.8 rems)	19 (61.2 rems)	3 (4.9 rems)	9 (28.1 rems)	14 (14.3 rems)
	Skin	2	23.5	--	--	--	--	2 (23.5 rems)
	Extremity	5	172	1 (86 rems)	--	2 (44 rems)		2 (42 rems)
1974	Whole Body	95*	1,000.3	29 (367.2 rems)	43 (155.9 rems)	8 (25.9 rems)	8 (34.2 rems)	7 (417.1 rems)
	Skin	1	8.9	--	--	--	--	1 (8.9 rems)
	Extremity	7	208	--	--	6 (186 rems)	1 (22 rems)	--
1975	Whole Body	31	121.2	11 (59.8 rems)	14 (44.2 rems)	3 (8.5 rems)	2 (3.3 rems)	1 (5.4 rems)
	Skin	1	8.1	--	--	--	--	1 (8.1 rems)
	Extremity	7	198	2 (74 rems)	3 (83 rems)	2 (41 rems)	--	--

*40 overexposures were reported by one power reactor when there were unanticipated discrepancies between the self-reading and film dosimeters.

Table 9-7. Summary of exposures to excessive concentrations *(9.12)*

Reported by NRC licensees pursuant to 10 CFR20.403 and 20.405

Calendar Year	Nuclides Involved	Number of Individuals	Number of Exposures per Licensed Activity: Power Reactors	Fuel Fab. & Processing	Fuel Reprocess.	Manuf. & Distrib.	Medical	Other
1971	I-125,-131,-133	27	17	--	--	9	--	1
	Uranium	35	--	26	6	--	--	3
	Pu-239	62	--	47	15	--	--	--
	H-3, C-14	6	--	--	--	3	--	3
	Mixture(Am,Sr, Pb,Ru,Cs,Co)	24	4	13	7	--	--	--
1972	I-125,-131	13	--	--	--	13	--	--
	Uranium	110	--	99	9	--	--	2
	Pu-239	34	--	25	--	--	--	9
	H-3	6	--	--	--	6	--	--
	Mixture(Am,Sr, Nb,Zr,Co,Pu)	4	1	1	1	1	--	--
1973	I-125,-131	7	--	--	--	4	--	3
	Uranium	45	--	26	19	--	--	--
	Pu-239	17	--	15	--	--	--	2
	H-3	4	--	--	--	4	--	--
	Mixture(Am,Sr, Co,Pu)	3	--	--	1	--	--	2
1974	I-125,-131	5	--	--	--	2	1	2
	Uranium	48	--	30	7	--	--	11
	Pu-239	10	--	10	--	--	--	--
	H-3	1	--	--	--	--	--	1
	Mixture(MFP, Am,Pu)	20	12	--	--	4	--	4
1975	I-125,-131	9	2	--	--	3	2	2
	Uranium	24	--	24	--	--	--	--
	Pu-239	23	--	21	--	--	--	2
	H-3	1	--	--	--	--	--	1
	Co-60	4	4	--	--	--	--	--
	Mixture(MFP)	1	1	--	--	--	--	--

Table 9-8. Exposure, personnel, and power generation summary for light water-cooled power reactors, United States, 1969-1975 *(9.15)*

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Person-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
ARKANSAS 1 Docket 50-313, DPR-51 1st commercial operation 8/74 Type - PWR Capacity - 850 MWe	75	588.0	147			46					0.31	0.1
BIG ROCK POINT Docket 50-155, DPR-6 1st commercial operation 3/63 Type - BWR Capacity - 72 MWe	69	43.2	165			136					0.82	3.1
	70	43.5	290			194					0.67	4.5
	71	44.4	260			184					0.7	4.1
	72	43.5	195			181					0.92	4.1
	73	50.9	119			336			140	196	2.8	6.6
	74	40.7	281			276	54	222	42	234	0.98	6.6
	75	35.1	216			180	58	122	20	160	0.83	5.1
BROWN'S FERRY 1 Docket 50-259, DPR-33 1st commercial operation 8/74 Type - BWR Capacity - 1065 MWe	75	328.9	2380			325					0.14	1.0
HADDAM NECK Docket 50-213, DPR-61 1st commercial operation 1/68 Type - PWR Capacity - 575 MWe	69	397.6	138	75	63	106			27	79	0.77	.5
	70	424.7	734	657	77	689			463	226	0.94	1.7
	71	502.2	289	216	73	342			166	176	1.18	.8
	72	515.6	355	285	70	325			181	144	.91	.7
	73	293.1	841	770	71	673			525	148	0.80	2.1
	74	519.1	550			201					0.37	.4
	75	494.3	795			669	19	650			0.84	1.4
COOPER STATION Docket 50-298, DPR-46 1st commercial operation 7/74 Type - BWR Capacity - 778 MWe	75	456.4	175	71	104	96	25	71	16	80	0.55	0.2

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Person-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
DRESDEN 1, 2, 3 Docket 50-10, 50-237, 50-249 DPR-10, 19, 25 1st commercial operation 7/60, 6/72, 11/71 Type - BWR Capacity MWE 200, 809, 809	69	89.4				286						3.2
	70	304.0				143						.5
	71	394.5				715						1.8
	72	1243.7				728						.6
	73	1172.2	1341			909	138	771	333	576	0.68	.8
	74	842.5	1594	318	1276	1662			57	1605	1.04	2.0
	75	708.1	3671	3076	595	3209	254	2955	2111	1098	0.87	4.5
FORT CALHOUN Docket 50-285, DPR-40 1st commercial operation 6/74 Type - PWR Capacity - 457 MWe	75	252.3	469	369	100	298			93	205	0.63	1.2
GINNA Docket 50-244, DPR-18 1st commercial operation 3/70 Type - PWR Capacity - 490 MWe	70	268.5	170	56	114	207	94	113	15	192	1.21	.8
	71	327.8	340	134	206	430	69	361	108	322	1.26	1.3
	72	295.6	677	266	411	1032	71	961	278	754	1.52	3.4
	73	409.5	421			244	60	184	91	153	0.58	.6
	74	253.7	884			1224					1.38	4.8
	75	365.2	558			496					0.89	1.4
HUMBOLDT BAY Docket 50-133, DPR-7 1st commercial operation 2/63 Type - BWR Capacity - 65 MWe	69	40.6	125	41	84	164	69	95	12	152	1.31	4.0
	70	49.3	115	35	80	209	130	79	37	172	1.81	4.3
	71	39.6	140	53	87	292	114	178	65	227	2.1	7.7
	72	43.1	127	54	73	253	81	172	57	196	1.99	5.9
	73	50.1	235			261	59	202			1.11	5.3
	74	43.4	296	221	75	318	103	215			1.07	7.1
	75	45.3	303	230	73	332	128	204	110	222	1.10	7.3
INDIAN POINT 1, 2 Docket 50-3, 50-247, DPR-5, 26 1st commercial operation 10/62, 8/73 Type - PWR Capacity - 265 MWe, 873 MWe	69	183.3				298						1.6
	70	43.3				1639						33.0
	71	154.0				768						5.0
	72	142.3				967						6.6
	73	0	2998			5134	692	4442	2778	2356	1.71	
	74	556.1	1019	114	905	910					0.89	1.6
	75	584.4	480	73	407	626	147	479	42	584	1.3	1.1

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Person-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
KEWAUNEE	75	401.9	54	23	41	25	1	24	11	14	.5	.06
Docket 50-305, DPR-43												
1st commercial operation 6/74												
Type - PWR												
Capacity - 560 MWe												
LACROSSE	71	33.1	218			158					0.72	5.0
Docket 50-409, DPR-45	72	29.2	151			172					1.13	5.9
1st commercial operation 9/69	73	24.4	157			221					1.41	9.1
Type - BWR	74	37.9	115	21	94	139	89	50	6	133	1.21	3.7
Capacity - 50 MWe	75	32.0	165			234					1.42	7.3
MAINE YANKEE	73	408.7	422	309	113	121			61	60	0.29	.3
Docket 50-209, DPR-36	74	432.6	620	485	135	420	64	356	188	232	0.68	1.0
1st commercial operation 12/72	75	542.9	577	418	159	347	16	331	197	150	0.60	0.6
Type - PWR												
Capacity - 790 MWe												
MILLSTONE POINT 1	72	377.6	612	487	125	596	50	546	340	256	0.97	1.6
Docket 50-245, DPR-21	73	225.1	1152	982	170	620	117	503	395	225	0.54	2.7
1st commercial operation 3/71	74	430.3	2477			1430					0.58	3.3
Type - BWR	75	465.4	2587			2022					0.78	4.3
Capacity - 690 MWe												
MONTICELLO	72	424.4	99	9	90	61	40	21	1	60	0.61	.1
Docket 50-363, DPR-22	73	389.5	276	145	131	154	42	112	59	95	0.56	.4
1st commercial operation 7/71	74	349.3	842	477	365	349			91	258	0.41	1.0
Type - BWR	75	344.8	1353			1353					1.0	3.9
Capacity - 545 MWe												
NINE MILE POINT	70	227.0	821	660	161	44	12	32	17	27	0.05	.2
Docket 50-220, DPR-63	71	346.5	1006	738	268	195	43	152	63	89	0.19	.6
1st commercial operation 12/69	72	381.8	735	450	285	285	59	226	28	198	0.38	.8
Type - BWR	73	411.0	550	318	232	517	127	390	108	409	0.94	1.3
Capacity - 610 MWe	74	385.9	740	463	277	824	42	782	279	545	1.11	2.1
	75	359.0	649	329	320	681	68	613	203	478	1.04	1.9

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Person-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
OCONEE 1, 2, 3 Docket 50-269, 270, 287 DRP-38, 47, 55 1st commercial operation 7/73, 9/74, 12/74 Type - PWR Capacity - 886, 886, 886 MWe	74	724.3	844	253	591	517	18	499	144	373	0.61	.7
	75	1838.3	541	112	429	457	66	391	83	374	0.84	.3
OYSTER CREEK Docket 50-219, DPR-16 1st commercial operation 12/69 Type - BWR Capacity - 650 MWe	69	40.1										
	70	413.6	95	32	63	63	21	42	11	52	0.66	.2
	71	448.9	249	164	85	240	50	190	92	148	0.96	.5
	72	515.0	339	242	97	582	150	432	167	415	1.71	1.1
	73	424.6	782	635	147	1236	195	1041	683	553	1.58	2.9
	74	434.5	935	346	589	984	166	818	162	822	1.05	2.[illegible]
	75	373.6	1210			1132	168	964	269	863	0.94	3.0
PALISADES Docket 50-255, DPR-20 1st commercial operation 12/71 Type - PWR Capacity - 821 MWe	72	216.8				78						
	73	286.8	901	608	293	1109	16	1093	647	462	1.23	3.8
	74	10.5	774			627					0.81	60
	75	300.2	474			292					0.62	0.97
PEACH BOTTOM 2, 3 Docket 50-277, 278, DPR 44, 56 1st commercial operation 12/74 Type - BWR Capacity - 1065, 1065 MWe	75	1234.3	971			228					0.24	0.18
PILGRIM Docket 50-293, DPR-35 1st commercial operation 12/72 Type - BWR Capacity - 655 MWe	73	484.0	53			74	29	45			1.4	.2
	74	234.1	454			415					0.91	1.8
	75	308.1	473			744	132	612	384	360	1.6	2.4

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Person-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
POINT BEACH 1 & 2 Docket 50-266, 301, DPR-24, 27 1st commercial operation 12/70, 4/73 Type - PWR Capacity - 497 MWe, 497 MWe	72	378.3				580						1.5
	73	693.7	729			570	70	500			0.78	.8
	74	760.2	400			295	70	225	81	214	0.74	.4
	75	801.2	339			456					1.3	0.6
PRAIRIE ISLAND 1, 2 Docket 50-282, 306, DPR-42, 60 1st commercial operation 12/73, 12/74 Type - PWR, PWR Capacity - 530 MWE, 530	74	181.9	150	56	94	18			5	13	0.12	.1
	75	836.0	477			123					0.26	0.15
QUAD CITIES 1 & 2 Docket 50-254, 265, DPR-29, 30 1st commercial operation 2/73, 3/73 Type - BWR Capacity - 809 MWe, 809 MWe	73	1209.6	533			201	28	173	59	142	0.37	.2
	74	958.1	678	488	190	482			36	446	0.71	.5
	75	833.6	1972	1418	554	1385	98	1287	592	793	0.70	1.7
ROBINSON Docket 50-261, DPR-23 1st commercial operation 3/71 Type - PWR Capacity - 707 MWe	71	295.3	283	242	41	364	7	357	351	13	1.28	1.2
	72	580.0	245	147	98	215	42	173	137	78	0.87	.4
	73	455.1	831			695					0.83	1.5
	74	578.1	853			672	185	487			0.78	1.2
	75	501.8	849			1142					1.35	2.3
SAN ONOFRE 1 Docket 50-206, DPR-13 1st commercial operation 1/68 Type - PWR Capacity - 450 MWe	69	289.8	123	32	91	42	10	32	5	37	0.34	.2
	70	365.9	251	92	159	155	13	142	59	96	0.61	.4
	71	362.1	121	12	109	50	12	38	3	47	0.41	.1
	72	372.2	326	141	185	256	29	227	117	139	0.78	.7
	73	273.7	878	547	331	329	37	292	157	172	0.37	1.2
	74	377.8	219			71					0.32	.2
	75	389.0	424			292					0.75	0.7

Reporting organization	Year	Power generated (MW-y)	Personnel			Dose rate (person-rem/y)					Average dose (rem per person)	Persoh-rem per MW-y
			Total	Contractor	Utility	Total	Operations	Maintenance	Contractor	Utility		
SURRY 1 & 2 Docket 50-280, 281, DPR-32, 37 1st commercial operation 12/72, 5/73 Type - PWR Capacity - 823 MWe, 823 MWe	73	829.4	936			152					0.16	.2
	74	717.4	1715			884	72	812			0.52	1.2
	75	1029.7	808			1549	25	1524	1000	549	1.91	1.5
THREE MILE ISLAND 1 Docket 50-289, DPR-50 1st commercial operation 9/74 Type - PWR Capacity - 819 MWe	75	675.9	168			83			21	62	0.49	0.1
TURKEY POINT 3 & 4 Docket 50-250, 251, DPR-31, 41 1st commercial operation 12/72, 9/73 Type - PWR Capacity - 745 MWe	73	565.9	444			78					0.18	.1
	74	966.4	794			454	88	366	202	252	0.57	.5
	75	1003.7	1175			875	270	605	558	317	0.74	0.87
VERMONT YANKEE Docket 50-271, DPR-28 1st commercial operation 11/72 Type - BWR Capacity - 514 MWe	73	222.1	244			85					0.35	.4
	74	303.5	357			216	24	192	103	113	0.61	.7
	75	429.0	247	164	83	139	64	75	57	82	0.56	.3
YANKEE ROWE Docket 50-29, DPR-3 1st commercial operation 7/61 Type - PWR Capacity - 175 MWe	69	123.1	193	117	76	215	46	169	78	91	1.1	1.8
	70	146.1	355	280	75	255	60	195	98	97	0.71	1.8
	71	173.5	155	60	95	90	44	46	19	71	0.58	.5
	72	78.7	282	210	72	255	60	195	147	108	0.90	3.2
	73	127.1	263	158	105	146			70	76	0.56	1.1
	74	111.3	243	149	94	205			99	106	0.84	1.8
	75	145.1	210	134	76	138	62	76	78	60	0.66	1.0
ZION 1, 2 Docket 50-295, 304, DPR-39, 48 1st commercial operation 12/73, 9/74 Type - PWR Capacity - 1050 MWe	74	425.3	306	87	219	56			13	43	0.18	.2
	75	1181.5	1433	938	495	117	16	101	45	72	.08	0.1

Table 9-8 shows the annual person-rem at each LWR power station for each year 1969-1975; where there is more than one reactor per station, the figure shown is the total for all units. Table 9-9 shows the whole body exposures by exposure ranges for calendar year 1975. The average exposure per reactor per year for all reactors and for PWR's and BWR's is shown in table 9-10. In 1975 an average of 578 persons per reactor received measurable exposure with an average exposure per individual of 0.8 rem (table 9-11). The number of persons at commercial reactors receiving exposures in excess of the limits established by 10 CFR Part 20 are reported in table 9-12.

Data on personnel and radiation exposure by work function are shown in tables 9-13 and 9-14. Routine and special maintenance continue to account for the major portion of in-plant exposure. The data accounts for approximately one-half of the total exposure received at LWR's during 1975 because not all data submitted by licensees could be categorized by the work function.

ERDA Standards for Radiation Protection are applicable to ERDA and ERDA contractor operations not subject to Nuclear Regulatory Commission licensing. The two basic requirements for all ERDA operations are: (1) that all operations are conducted in a manner to assure that radiation exposure to individuals and population groups is limited to the lowest levels technically and economically practicable, and (2) that radiation exposure to individuals or population groups be maintained below prescribed limits. The prescribed limits for occupationally exposed individuals are given in table 9-1.

Table 9-15 gives annual whole body exposure data for ERDA and its contractors for the past 12 years. The number of people monitored by ERDA has decreased over the period but that is not necessarily a good indicator of the number of radiation workers because contractors have some flexibility as to whom they monitor. The increase in total number of workers monitored in 1975 does reflect increased employment in a few technical programs.

Table 9-16 gives information on trends in higher exposures. The percent of employees with high dose equivalents increased somewhat in 1975 and in table 9-17 the source of this increase is more evident. The increase in dose equivalent in the Oak Ridge Operations Office is due primarily to the expansion of the gaseous diffusion plant capability; at Pittsburgh Naval Reactors, the replacement of a steam generator and major plant modification for installation of the light water breeder reactor (LWBR) core at the Shippingport Atomic Power Station contributed to the increase; at Schenectady Naval Reactors, the increase was due to the overhaul, refueling, and modification of naval prototype reactor plants to test newly designed naval reactor plant components. It is expected that radiation exposures will diminish when some of the work is completed.

Table 9-9. Dose received by occupationally exposed personnel at licensed nuclear power facilities - calendar year 1975 whole body exposures (per 10 CFR 20.407 reports) *(9.15)*

Plant Name and License No.	No Measurable Exposure	Measurable <100	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	TOTALS
			Exposure Ranges (Rem)													
Dresden 1, 2, 3 DPR's-2, 19, 25	1,687	403	210	156	125	153	629	306	166	109	29	24				3,997
Yankee-Rowe DPR-3	1,572	95	19	42	21	48	23	1								1,821
Big Rock Point DPR-6	34	137	60	26	12	7	23	24	6	4	1					334
Humboldt Bay DPR-7	38	100	28	10	15	9	25	29	22	27						303
Peach Bottom 1, 2, 3 DPR's-12, 44, 56	1,527	511	209	148	41	19	39	4								2,498
San Onofre 1 DPR-13	393	124	63	72	43	27	51	34	9	1						817
Oyster Creek DPR-16	264	439	157	119	69	59	202	56	43	26	25	10	4	1		1,474
R. E. Ginna DPR-18	151	127	93	93	68	74	206	20	4							836
Palisades DPR-20	149	204	70	51	36	29	57	38	9	1						644
Millstone 1, 2 DPR's-21, 65	908	686	629	354	212	99	317	130	70	48	22	10	7	3		3,495
Monticello DPR-22	434	246	140	228	124	92	369	79	37	25	7	4	2			1,787

Exposure Ranges (Rem)

Plant Name and License No.	No Measurable Exposure	Measurable <100	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	TOTALS
H. B. Robinson 2 DPR-23	599	230	50	55	52	67	138	172	33	30	21	1				1,448
Point Beach 1, 2 DPR's-24, 27	274	65	32	32	27	17	79	46	19	16	5	1				613
Vermont Yankee DPR-28	773	60	87	42	24	27	27	13	2							1,055
Turkey Point 3, 4 DPR's-31, 41	849	361	173	117	130	71	211	82	22	8	1					2,025
Surry 1, 2 DPR's-32, 37	580	813	145	158	108	98	314	247	33	18	7	6	1			2,528
Quad Cities 1, 2 DPR's-29, 30	1,225	113	64	108	74	92	337	183	56	33	23					2,308
Brown's Ferry 1, 2 DPR's-33, 52	2,085	1,638	457	180	57	20	28									4,465
Ft. St. Vrain DPR-34	1,263															1,263
Pilgrim DPR-35	324	102	57	29	30	17	83	65	42	13	12	4	10	8	(10-11) 1	797
Maine Yankee DPR-36	233	168	44	32	38	30	84	39	5							673
Oconee 1, 2, 3 DPR's-38, 47, 55	255	275	163	117	61	47	102	47	15	2						1,084

Exposure Ranges (Rem)

Plant Name and License No.	No Measurable Exposure	Measurable <100	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	TOTALS
Calvert Cliffs 1 DPR-53	570	670	41	43	22	6	1									1,353
Rancho Seco DPR-54	1,055	149	43	19	3	1	1									1,271
Edwin Hatch 1 DPR-57	477	231	88	37	25	11	9	1	1	1						851
D. C. Cook 1 DPR-58	590	100	32	23	7	5	3									760
Fitzpatrick DPR-59	754	167	74	29	17	9	9									1,059
Haddam Neck DPR-61	370	181	91	90	87	54	193	93	6							1,165
Brunswick DPR-62	1,787	343	54	23	11	7	6									2,231
Nine Mile Point DPR-63	641	193	99	59	27	33	119	50	37	23	9					1,290

Exposure Ranges (Rem)

Plant Name and License No.	No Measurable Exposure	Measurable <100	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	TOTALS
Zion 1, 2 DPR's-39, 48	1,260	147	118	98	35	26	12									1,696
Ft. Calhoun DPR-40	153	192	63	54	26	20	73	34	7							622
Prairie Island 1, 2 DPR-42	234	316	57	33	17	14	38	2								711
Kewaunee DPR-43	143	56	18	16	6	2	5	1								247
LaCrosse DPR-45	60	40	20	17	4	5	25	23	19	12						225
Cooper Station DPR-46	407	404	73	40	23	12	23	4								986
Duane Arnold DPR-49	1,409	105	75	24	8	6	5									1,632
Indian Point 1, 2 DPR's-5, 26	744	330	141	88	57	53	110	49	29	27	7					1,635
Three Mile Island DPR-50	0*	0*	0*	78	31	15	6	1								131
Arkansas 1 DPR-51	488	87	44	8	5	3										635

* Did not report those personnel not required to be monitored.

Table 9-10. Dose summary of licensed nuclear power facilities, 1969-1975 *(9.15)*

a. All light water reactors

Year	Number of reactors	Average rated capacity [MW(e)]	Yearly average person-rem/ reactor-year
1969	7	267	178
1970	10	362	365
1971	13	401	294
1972	18	472	364
1973	26	546	534
1974	32	581	427
1975	44	640	457
b. Pressurized water reactors			
1969	4	381	165
1970	5	403	599
1971	6	459	340
1972	8	500	463
1973	12	575	772
1974	18	625	364
1975	26	650	309
c. Boiling water reactors			
1969	3	116	195
1970	5	322	130
1971	7	351	255
1972	10	450	286
1973	14	521	330
1974	14	521	507
1975	18	626	670

Table 9-11. Average occupational radiation exposure per individual for licensed nuclear power facilities, 1969-1975 *(9.15)*

Year	Average exposure per individual (rem)	Average number of personnel per reactor
1969	1.1	141
1970	1.0	305
1971	1.0	302
1972	1.2	344
1973	0.9	584
1974	0.8	515
1975	0.8	578

Table 9-12. Overexposures at commercial power reactors *(9.15)*

Year	Number of overexposures to external radiation	Whole body person-rem involved	Whole body maximum exposure (rem)	Number of reports of exposure to excessive concentration of radioactive material	Maximum exposure
1971	2	4.5	3.1	21	6.052 rem (thyroid)
1972	16	49.7	5.1	2	2000 MPC-h
1973	19	61.2	4.0	0	
1974	43	155.9	6.1	12	433 MPC-h
1975	14	44.2	3.8	7	13.5 rem (lung)

Table 9-13. Number of personnel and dose by work function at licensed nuclear power facilities, 1975 *(9.15)*

a. Number of employees (>100 mrem/y)

Work function	Station employees	Utility employees	Contract workers and others	Total
Reactor operations	1105	81	143	1329
Routine maintenance	2118	198	6330	8646
Inservice inspection	250	99	251	600
Special maintenance	752	429	1204	2385
Waste processing	520	63	521	1104
Refueling	306	10	156	472
Totals	5051	880	8605	14536

b. Total dose (person-rem)

Work function	Station employees	Utility employees	Contract workers and others	Total
Reactor operations	1136	13	60	1209
Routine maintenance	2134	267	3466	5867
Inservice inspection	60	63	207	330
Special maintenance	705	423	999	2127
Waste processing	635	19	120	774
Refueling	449	127	289	865
Totals	5119	912	5141	11172

Table 9-14. Percentages of personnel and exposure by work function at licensed nuclear power facilities, 1975 *(9.15)*

Work function	Personnel			Exposure		
	Utility	Contractor	Total	Utility	Contractor	Total
Reactor operations and surveillance	8.2	1.0	9.2	10.3	0.5	10.8
Routine maintenance	16.0	43.5	59.5	21.5	31.1	52.6
Inservice inspection	2.4	1.7	4.1	1.2	1.8	3.0
Special maintenance	8.1	8.2	16.3	10.1	8.9	19.0
Waste processing	4.0	3.6	7.6	5.8	1.1	6.9
Refueling	2.3	1.0	3.3	5.1	2.6	7.7
TOTAL	41	59	100	54	46	100

Table 9-15. Whole body radiation exposure history for ERDA and ERDA contractor employees *(9.16)*

	NUMBER OF ESTIMATED DOSE EQUIVALENTS IN EACH OF FOLLOWING RANGES (rem)												TOTAL
YEAR	0-1*	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12	MONITORED
1964	122711	3583	1823	575	176	43	20	10	7	6	10	1		128965
1965	128360	4158	1704	515	294	70	32	26	25	22	6	2		135214
1966	130552	3706	1630	597	313	88	47	24	6	2			1	137939
1967	102510	3472	1572	555	168	35	29	23	17	4	1			108386
1968	103206	2799	1408	425	144	3	1							107996
1969	98625	2554	1313	335	86	4					1			102918
1970	92185	2698	1329	279	158	5	4	2		1				96661
1971	90640	2380	888	275	118	8	3				1		2	94315
1972	86077	2130	929	219	95	8	2							89460
1973	89071	1944	727	172	60	2	1							91977
1974***	75706	1689	692	149	40	4								78232
1975	85451	1846	753	232	142				1					88425

*In 1975, approximately 65 percent of these employees received a dose equivalent which was less than measurable.

**Data for 1966 and 1967 differ from previous reports due to the discovery of an error in the radiation exposure records of one major contractor.

***These data differ slightly from that reported in ERDA-76/119 because of the late reporting of exposures for 227 individuals.

Table 9-16. Whole-body exposure history of ERDA and ERDA contractor employees *(9.16)*

Year	Percent of employees with dose equivalent greater than 1 rem (number)		Total (person-rem)[a]	Total monitored
	1 rem (number)	2 rem (number)		
1964	4.85 (6254)	2.07 (2671)	13411	128965
1965	5.07 (6854)	1.99 (2696)	14818	135214
1966[b]	5.35 (7387)	1.98 (2738)	15454	137939
1967[b]	6.11 (6622)	2.23 (2415)	13715	108386
1968	4.43 (4780)	1.83 (1981)	9877	107986
1969	4.17 (4293)	1.69 (1739)	8707	102918
1970	4.63 (4476)	1.84 (1778)	9137	96661
1971	3.90 (3675)	1.37 (1295)	5395	94315
1972	3.78 (3383)	1.40 (1253)	6170	89460
1973	3.16 (2906)	1.05 (962)	5623	91977
1974[c]	3.26 (2549)	1.13 (882)	4935	78232
1975	3.36 (2974)	1.28 (1128)	5813	88425

[a] Individuals with dose equivalent of less than 1 rem have been excluded. In 1975, this represented approximately 50 percent of the total person-rem. Therefore, these data reflect only the trend in high ranges of dose equivalents rather than the total collective dose equivalent.

[b] Data for 1966 and 1967 differ from previous reports due to the discovery of an error in the radiation exposure records of one major contractor.

[c] These data differ slightly from that reported in ERDA-76/119 because of the late reporting of exposures for 227 individuals.

Table 9-17. Occupational dose equivalent for 1974-1975 by ERDA Field Office *(9.16)*

Field office	Person-rem		Change
	1974	1975	(percent)
Albuquerque	2405	2324	-3
Chicago	1943	1638	-17
Grand Junction	--	5	--
Idaho	686	611	-11
Nevada	58	55	-5
Oak Ridge	1178	1284	+9
Pittsburgh Naval Reactors	587	1876	+220
Richland	2079	2257	+8
San Francisco	320	283	-12
Schenectady Naval Reactors	261	1022	+292
Savannah River	1484	1268	-15
TOTAL	11001	12622	+15

A breakdown of the 1975 whole-body dose equivalents by type of facility is given in table 9-18. Employees working in reactor, fuel reprocessing, and accelerator facilities continue to receive the highest average exposures. General research and other facilities, which accounts for 50 percent of the total dose equivalent, includes many employees who more appropriately should be reported under another facility type. This category should include only those who received their radiation exposures from a variety of sources. Average exposure per individual by type of facility is shown in table 9-19.

Only one ERDA contractor employee received a whole-body exposure greater than the limit of 5 rem during 1975. The exposure of 8-9 rem as measured by the workers' dosimeter occurred in a well-type gamma-ray calibration facility. ERDA contractors reported that 48 workers in 1975 were determined to have radioactive material deposited in their bodies which produced 50 percent of the annual dose equivalent standard for a critical organ (table 9-20) *(9.16)*.

The ERDA also operates the U.S. Transuranium Registry (USTR), a center collecting precise information about the occupational effects of transuranium elements on man. Participation in this registry, which was established by the Atomic Energy Commission in 1968, is completely voluntary on an individual basis and includes release of medical and health physics data. Permission is also obtained on a voluntary basis for post mortem analyses of tissues of interest. The principal criterion used by USTR to determine the inclusion of an individual in the registry is that the employer provides a routine surveillance program because of a reasonable likelihood that exposure could occur.

Each of the major ERDA facilities participates in the registry, including Hanford, Savannah River Plant, Rocky Flats, Los Alamos, Mound Laboratory, and Oak Ridge as well as NRC licensees.

As of October 1, 1976, a total of 13,943 United States transuranium workers have been included in registry data. Table 9-21 indicates the number of workers identified, health physics and medical releases obtained, autopsy permissions obtained, autopsies completed and autopsy reports completed. For comparison, table 9-22 shows the same data for the previous year. The large number of workers identified for the registry in 1976 was due to the completion of a study to identify workers employed before 1958 and terminating before January 1, 1976 *(9.17)*.

Most of the data on occupational exposure to plutonium comes from medical followup data on military personnel who worked with plutonium in 1944-45 at Los Alamos. Hempelmann et al. reported that "to date, none of the medical findings in the group can be attributed definitely to internally deposited plutonium" *(9.18)*. The selected cases shown in table 9-23 represent systemic plutonium burdens ranging from 0.13 to 0.42 Ci, which correspond to annual bone doses of approximately 2 to 6 rad *(9.19)*.

Table 9-18. Distribution of annual whole body exposures for all ERDA and ERDA contractor employees *(9.16)*

FACILITY TYPE	TOTAL MONITR	< MEAS.	<0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.75 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12	TOTAL PERSON-REM
								EXPOSURE RANGES (REM)												
REACTOR	3812	1062	882	427	427	258	146	299	238	50	3									1800
FUEL FAB	1050	74	519	190	155	55	27	25	5											225
FUEL PROC	1865	285	619	245	224	140	108	170	61	13										793
URAN ENRCH	7471	1607	5236	2[illegible]	105	29	6	6												383
WEAPON FBT	19425	11579	4365	2341	594	224	113	181	24	4										1435
IRRAD FACL																				
GEN RESRCH	33769	19430	9242	2453	1184	510	330	484	118	14	3				1					3035
ACCELERATR	7384	5002	1161	446	247	135	81	176	72	45	19									1071
OTHER	11479	2340	6055	876	651	343	253	503	235	106	117									3375
VISITORS	58946	54190	3764	750	157	40	20	21	4											462
ERDA OFFCS	2170	1711	376	51	23	5	2	2												44
TOTAL	147371	97500	32219	8061	3767	1739	1086	1867	757	232	142				1					12623

Table 9-19. Dose per facility type for ERDA and ERDA contractor employees, 1975 *(9.16)*

FACILITY TYPE	TOTAL NO. INDIVIDUALS MONITORED	NO. INDIVIDUALS WITH MEASURABLE EXPOSURE	TOTAL NO. PERSON-REM	AVERAGE EXPOSURE (REM) PER INDIVIDUAL (BASED ON ALL EXPOSURES)	AVERAGE EXPOSURE (REM) PER INDIVIDUAL (BASED ON MEASURABLE EXPOSURES)
REACTOR	3812	2730	1800	.47	.66
FUEL FAB	1050	976	225	.22	.23
FUEL PROC	1865	1580	793	.43	.50
URAN ENRCH	7471	5664	383	.05	.07
WEAPON F&T	19425	7846	1435	.07	.18
IRRAD FACL	0				
GEN RESRCH	33769	14339	3035	.09	.21
ACCELERATR	7384	2382	1071	.15	.45
OTHER	11479	9139	3375	.29	.37
VISITORS	58946	4756	462	.01	.10
ERDA OFFCS	2170	459	44	.02	.10

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Table 9-20. Summary of exposures resulting in internal body depositions of radioactive materials for calendar year 1975 for ERDA and ERDA contractor employees *(9.16)*

Nuclide	Organ	Dose (rem)									
		0-5	5-10	10-15	15-20	20-25	25-30	30-50	50-100	100-200	200-300
$^{239-240}$Pu	Bone										
$^{238-239-240}$Pu	Bone				2	1					
$^{239-240-241}$Pu	Lung				1						
$^{239-240}$Pu, ^{241}Am	Lung		6								
^{235}U	Lung		2	1							
$^{234-235}$U	Lung		4	4							
$^{234-235-238}$U	Lung			20	6						
$^{234-238}$U	Lung			1							

Table 9-21. U.S. transuranium registry, 1976 (*9.17*)

Contractors	Transuranium workers identified			Health effects and medical releases			Authority for autopsy			Autopsies obtained			Autopsy reports complete		
	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date
Hanford	4634	4648	6966	0	12	2146	0	1	525	2	7	22	0	2	10
Rocky Flats	19	141	1913	19	139	1750	0	5	177	0	2	36	0	0	30
Los Alamos	0	0	3024	0	0	257	0	0	127	0	0	4	0	1	2
Savannah River	9	9	1576	0	0	0	0	0	0	0	0	0	0	0	0
Mound	0	0	333	0	0	8	0	0	9	0	0	1	0	0	1
Oak Ridge	13	13	14	0	0	0	0	0	0	0	0	1	0	0	1
Subtotal	4675	4811	13,826	19	151	4161	0	6	838	2	9	64	0	3	44
Licensees															
Richland Energy Lab	0	0	13	0	0	9	0	1	2	0	1	1	0	0	0
Exxon Nuclear	0	1	42	0	1	32	0	1	8	0	0	0	0	0	0
Babcock & Wilcox	0	61	61	0	61	61	0	2	2	0	0	0	0	0	0
Nuclear Fuel Services, Inc.	0	1	1	0	1	1	0	1	1	0	0	0	0	0	0
Total	4675	4874	13,943	19	214	4264	0	11	851	2	10	65	0	3	44

Table 9-22. U.S. transuranium registry, 1975 (*9.17*)

Contractors	Transuranium workers identified			Health physics and medical releases			Authority for autopsy			Autopsies obtained			Autopsy reports complete		
	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date	Mo. Sep.	Calendar year to date	Total to date
Hanford	2	37	2367	2	37	2174	0	8	533	0	0	14	0	0	8
Rocky Flats	0	40	1772	0	40	1611	0	6	173	1	4	34	0	0	28
Los Alamos	0	2765	3024	0	0	257	0	0	127	0	2	3	0	0	0
Savannah River	0	8	1567	0	0	0	0	0	0	0	0	0	0	0	0
Mound	0	0	333	3	4	8	3	4	9	0	0	1	0	0	1
Oak Ridge	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	2	2850	9063	5	81	4050	3	18	842	1	6	53	0	0	38

Summary

Occupational and industrial radiation protection programs are concerned with the exposure of individuals to a radiation environment during their occupations. There are approximately 3.7 radiation workers per 1,000 people in the United States, and in 1970 the average annual individual occupational dose was 0.8 mrem/y.

The data indicate that the largest occupational exposures generally are received by waste disposal workers and, to a lesser extent, by industrial radiographers.

The highest occupational personnel exposures from U.S. operating nuclear power plants for the period 1969-1975 have resulted from inplant maintenance activities.

The yearly average person-rem per reactor year at pressurized water reactors was 309 for 1975, a decrease from the previous year; for boiling water reactors, the yearly average person-rem per reactor year had increased in 1975 to 670 from 507 in 1974.

Table 9-23. Plutonium systemic body burden estimates for selected Manhattan project plutonium workers at three different times[a] *(9.19)*

	$^{239\text{-}240}$Pu (nCi)		
CASE CODE	1953	1962	1972
1	30-60	10	210
3	80	130	420
4	80	140	260
5	80	140	180
6	60	70	140
7	60	80	150
17	40	90	130

[a] PERSONS WITH MORE THAN 120 nCi $^{239\text{-}240}$Pu SYSTEMIC BURDEN IN 1972.

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Chapter 10 - Radioactivity in Consumer Products

Smoke detectors for homes and digital wristwatches are recent arrivals on the market of consumer products containing radioactive materials, whereas, artificial teeth and dinnerware containing these materials have been in use for some time. However, information has recently become available as to the amount of radiation exposure these products contribute to the members of the general population.

In addition to the consumer products containing or producing radiation discussed in this report, it is recommended that the reader refer to the previous Radiological Quality of the Environment report for additional sources of radiation exposure *(10.1)*. Sources discussed in the last report included television sets and timepieces containing radioactive material.

Radioactivity in digital wristwatches

Electronic digital watches are a viable consumer product offering many advantages over the traditional mechanical timepieces. The two technologies used in the digital electronic watch market are LED's (for light emitting diodes) which give a readout on demand and LCD's (for liquid crystal display) which give a continuous readout.

The LCD is a passive display meaning that it does not emit light but instead attenuates existing light. This is accomplished by utilizing a thin film of specifically oriented liquid crystal material whose interaction with polarized light and an electric field is the basis for the display operation. The advantage of the LCD is that it requires very little power to operate but its usefulness is limited by its lack of visibility under low level lighting conditions.

In February of 1976, the first LCD watch utilizing sealed tritium luminous sources appeared on the market. This display results in a truly legible display under all lighting conditions. It consist of a hollow glass tube whose inside walls are coated with an inorganic phosphor and then evacuated and back filled with tritium gas and laser-sealed. The radioactive decay of the tritium gas releases a low energy beta which in turn transfers its energy to the phosphor which then releases this excess energy in the form of light. These tubes, placed behind a liquid crystal display, result in a self-contained lighting system completely independent of external power. The total tritium content of these tubes is 200 mCi or less per watch *(10.2)*.

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Although the tubes have a diffusion rate of less than 0.1 μCi/24 hours, tests have shown that in general the watches exhibit a diffusion rate of less than 0.01 μCi/24 hours which is equal to less than 0.5 mrem per year. However, the watches are constructed to make tube breakage unlikely and to prevent the curious consumer from reaching the tubes themselves.

Radioactive materials in ceramic glazes

Uranium has been used as a coloring agent in glazes and glass since the 18th century. In the 19th century, these materials were discovered to be radioactive as a result of their fogging of photographic film. However, various combinations of uranium salts and oxides were utilized to render a variety of colors and fluorescences to a wide variety of glassware early in the 20th century.

In 1961, the Atomic Energy Commission permitted the use of "exempt" quantities of uranium not to exceed 20 percent in the glaze of ceramic tableware and no more than 10 percent in glassware. The AEC did not consider these levels of uranium to be a significant radiation hazard.

In 1971, the Bureau of Food in the Food and Drug Administration (FDA) conducted radiation measurements and 24-60 hour "soak" experiments using 4 percent acetic acid solutions to duplicate storage of certain "acid foods" such as sauerkraut, etc. They found a concentration of 55 ppm uranium and 66 ppm lead in the 60-hour leach solution.

The Bureau of Radiological Health, FDA concluded that the radiation levels, although low, constituted an unnecessary and avoidable exposure to the public. Based on the leach data, such dishware is also subject to the food additives clause of the Food, Drug and Cosmetic Act and subject to its regulations.

In 1974, the Nuclear Regulatory Commission used a "CONDOS" model *(10.3)* and a computer code to estimate the population exposure to the distribution, use and disposal of a variety of consumer products containing radioactive material *(10.4)*. Tableware that was assumed to contain 20 percent natural uranium in the glaze was included in the study. With all the parameters considered, dishwashers, waiters and patrons were the only subjects receiving measurable doses. In terms of whole body doses, dishwashers received 34.4 mrem/y, waiters 7.93 mrem/y and patrons 0.18 mrem/y.

As a result of adverse publicity and the threat of regulatory controls, manufacturers no longer use uranium as a color additive. However, tableware containing uranium in its glaze is still available in antique shops as collectors' items.

Smoke detectors containing radioactive material

Modern smoke detectors give early warnings of incipient fire conditions and this is an effective means of reducing the loss of lives and property from fires. The ionization chamber smoke detector uses radioactive material to ionize the air in its sensing chamber, permitting the flow of electrical current. Visible and invisible smoke particles produced by initial thermal decomposition, upon entering the sensing chamber, change the electrical characteristics of the ion flow, resulting in the sounding of an alarm.

Although radium-226 was originally used and is still used by a few small manufacturers, americium-241 is now the most widely used source material for ionizing radiation in smoke detectors. ^{241}Am, in the form of americium oxide, is mixed with gold and contained in a thin metal foil with silver and gold backing and cover. The foil, in the form of small strips or discs, is fixed mechanically to source holders which are then mounted in the smoke detectors.

Smoke detectors for use in commercial and industrial properties typically contain 15 microcuries (μCi) of ^{241}Am. Whereas the single units used in homes contain 1 μCi or less of ^{241}Am or, in the few cases where used, 0.1 μCi of radium-226 *(10.5)*.

The U.S. population is expected to be 287,000,000 in the year 2000. Assuming that 50 percent of the living units will have 2 ionization chamber smoke detectors per unit and that there will be 2.75 persons per unit, the calculated average individual dose rate will be 7.4 μrad/y and the calculated average population dose rate will be 1.4 μrad/y.

The Nuclear Regulatory Commission (NRC) estimates that a home ionization smoke detector held within 10 inches of the body for eight hours a day, every day for a year, will expose a person to only 1/10 of the radiation received in a roundtrip flight across the United States.

All U.S. manufacturers of smoke detectors containing ^{241}Am operate under license from the NRC and comply with its requirements and regulations for manufacturing and distribution of their products. Thus, the benefits to be gained from the use of ionization chamber smoke detectors outweigh the risks that might be involved.

Uranium in dental porcelain

For over half a century, the manufacturers of artificial teeth have added uranium salts to porcelain in an attempt to match coloring and fluorescence of natural teeth under all lighting conditions. While the resulting porcelain tooth matches the function, durability, and appearance of the natural tooth, its accompanying risks are not known.

The Bureau of Radiological Health (BRH) of the Food and Drug Administration conducted a study on the radiation hazards of porcelain in dental prostheses. The data from that study were published as a technical report in September 1976 *(10.6)*. Eighteen sets of artificial teeth and 23 powders submitted by domestic and foreign manufacturers were analyzed for alpha emissions, beta emissions, and uranium concentrations (Table 10-1).

Uranium concentrations in the porcelain teeth ranged from less than 0.001 to 0.044 percent. According to NRC, sources containing less than 0.050 percent uranium do not require a license to possess or use. The alpha dose rate for the set of teeth with highest uranium concentration was calculated to be 137 mrem per year. However, this dose was based on the assumption of intimate and continuous contact between teeth and oral tissues. This assumption is not valid because saliva and other absorbers are always present and many prostheses are not worn continuously. It was also observed that alpha doses are absorbed entirely in the superficial layer of the tissue and do not penetrate to the basal layer; thus, the possibility of producing a malignancy is minimized.

The dose rate for the more penetrating beta particles was calculated by determining the fraction of the measured flux resulting from uranium and the fraction resulting from potassium-40, which is a naturally occurring component of porcelain. This resulted in a beta dose rate ranging from 0.00 to 1.19 rem per year for uranium and from 0.08 to 0.2 rem/year for potassium-40 (table 10-2). Although these values may be considered overestimates because of the assumption of continuous contact between teeth and tissues, the dose reduction would not be as great as with the alphas because of the deeper penetration of the high energy beta particles.

Although the radiation dose from the amount of uranium presently used in artificial teeth does not create a significant health hazard, the dental industry has been urged by BRH to find a nonradioactive substitute within a reasonable period. Until a practical substitute for uranium becomes available, BRH has recommended a maxiumum permissible concentration of uranium in dental porcelain of 0.037 percent. This would reduce the probability that the dose from artificial teeth might exceed the 1.5 rem per year limit set by the International Commission on Radiation Protection.

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Table 10-1. Uranium concentration in dental porcelain *(10.6)*

Porcelain teeth		Porcelain powders	
Sample no.	Percent uranium	Sample no.	Percent Uranium
1	0.030	A	0.040
2	0.037	B	(a)
3	0.017	C	0.019
4	0.019	D	0.099
5	0.037	E	0.013
6	0.001	F	0.023
7	0.044	G	0.006
8	<0.001	H	0.003
9	0.007	I	0.017
10	0.037	J	0.027
11	0.003	K	0.025
12	0.020	L	0.053
13	0.044	M	0.027
14	0.028	N	0.002
15	0.008	O	0.035
16	0.025	P	0.019
17	0.037	Q	0.028
18	0.003	R	0.007
		S	0.038
		T	(a)
		U	(a)
		V	0.022
		W	0.017

[a] Sample too small to yield significant count rate over background.

Table 10-2. Annual dose from beta particle fluxes of porcelain teeth *(10.6)*

	Dose (rem/y)		
	^{238}U	^{40}K	Total
1	0.81	0.18	0.99
2	1.00	0.19	1.19
3	0.46	0.18	0.64
4	0.51	0.16	0.67
5	1.00	0.17	1.17
6	0.03	0.13	0.16
7	1.19	0.17	1.36
8	0.00	0.14	0.14
9	0.19	0.08	0.27
10	1.00	0.17	1.17
11	0.08	0.16	0.24
12	0.54	0.16	0.70
13	1.19	0.20	1.39
14	0.76	0.18	0.94
15	0.22	0.16	0.38
16	0.68	0.16	0.84
17	1.00	0.19	1.19
18	0.08	0.14	0.22

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Chapter 11 - Health Effects of Ionizing Radiation Exposure

Potential health effects from exposures to ionizing radiation are evaluated in this section. In order to make the interpretation of these estimated health effects more meaningful, the various health effect risk factors that can be applied will be presented.

No attempt has been made to assign individual exposure values to the various health effects for the following reasons. First, then, is a degree of uncertainty for the doses from different radiation sources. Although reported doses are based on actual data whenever possible, many of the values represent estimates having a large degree of variability. A second constraint on estimating potential health effects is the lack of definitive information on population parameters, especially where exposures are reported for specific facilities. This is important as there are differences in sensitivity; for example, children are more radiosensitive than adults. Therefore, while one might apply such risk conversion factors to large population groups where some generalizations as to population parameters are applicable, it is invalid to apply such generalizations when the population under consideration becomes smaller and more specific. Besides these two prime reasons, others, such as the lack of information on the pathway of exposure in many cases, have led to the decision to handle health effects in this general manner.

EPA has adapted the policy of assuming a linear relationship between the population exposure to ionizing radiation and its biological effect. This policy was issued on March 3, 1975, and is included here in its entirety.

"EPA Policy Statement on
Relationship Between Radiation Dose and Effect
41 FR 28409

"The actions taken by the Environmental Protection Agency to protect public health and the environment require that the impacts of contaminants in the environment or released into the environment be prudently

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examined. When these contaminants are radioactive materials and ionizing radiation, the most important impacts are those ultimately affecting human health. Therefore, the Agency believes that the public interest is best served by the Agency providing its best scientific estimates of such impacts in terms of potential ill health.

"To provide such estimates, it is necessary that judgments be made which relate the presence of ionizing radiation or radioactive materials in the environment, i.e., potential exposure, to the intake of radioactive materials in the body, to the absorption of energy from the ionizing radiation of different qualities, and finally to the potential effects on human health. In many situations, the levels of ionizing radiation or radioactive materials in the environment may be measured directly, but the determination of resultant radiation doses to humans and their susceptible tissues is generally derived from pathway and metabolic models and calculations of energy absorbed. It is also necessary to formulate the relationships between radiation dose and effects; relationships derived primarily from human epidemiological studies but also reflective of extensive research utilizing animals and other biological systems.

"Although much is known about radiation dose-effect relationships at high levels of dose, a great deal of uncertainty exists when high level dose-effect relationships are extrapolated to lower levels of dose, particularly when given at low dose rates. These uncertainties in the relationships between dose received and effect produced are recognized to relate, among many factors, to differences in quality and type of radiation, total dose, dose distribution, dose rate, and radiosensitivity, including repair mechanisms, sex, variations in age, organ, and state of health. These factors involve complex mechanisms of interaction among biological, chemical, and physical systems, the study of which is part of the continuing endeavor to acquire new scientific knowledge.

"Because of these many uncertainties, it is necessary to rely upon the considered judgments of experts on the biological effects of ionizing radiation. These findings are well-documented in publications by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Academy of Sciences (NAS), the International Commission on Radiological Protection (ICRP), and the National Council on Radiation Protection and Measurements (NCRP), and have been used by the Agency in formulating a policy on relationship between radiation dose and effect.

"It is the present policy of the Environmental Protection Agency to assume a linear, nonthreshold relationship between the magnitude of the radiation dose received at environmental levels of exposure and ill health produced as a means to estimate the potential health impact of actions it takes in developing radiation protection as expressed in criteria, guides, or standards. This policy is adopted in conformity with the generally accepted assumption that there is some potential ill health attributable to any exposure to ionizing radiation and that the magnitude of this potential ill health is directly proportional to the magnitude of the dose received.

"In adopting this general policy, the Agency recognizes the inherent uncertainties that exist in estimating health impact at the low levels of exposure and exposure rates expected to be present in the environment due to human activities, and that at these levels, the actual health impact will not be distinguishable from natural occurrences of ill health, either statistically or in the forms of ill health present. Also, at these very low levels, meaningful epidemiological studies to prove or disprove this relationship are difficult, if not practically impossible, to conduct. However, whenever new information is forthcoming, this policy will be reviewed and updated as necessary.

"It is to be emphasized that this policy has been established for the purpose of estimating the potential human health impact of Agency actions regarding radiation protection, and that such estimates do not necessarily constitute identifiable health consequences. Further, the Agency implementation of this policy to estimate potential human health effects presupposes the premise that, for the same dose, potential radiation effects in other constituents of the biosphere will be no greater. It is generally accepted that such constituents are no more radiosensitive than humans. The Agency believes the policy to be a prudent one.

"In estimating potential health effects, it is important to recognize that the exposures to be usually experienced by the public will be annual doses that are small fractions of natural background radiation to at most a few times this level. Within the United States, the natural background radiation dose equivalent varies geographically between 40 to 240 mrem per year. Over such a relatively small range of dose, any deviations from dose-effect linearity would not be expected to significantly affect actions taken by the Agency, unless a dose-effect threshold exists.

"While the utilization of a linear, nonthreshold relationship is useful as a generally applicable policy for assessment of radiation effects, it is also EPA's policy in specific situations to utilize the best available detailed scientific knowledge in estimating health impact when such information is available for specific types of radiation, conditions of exposure, and recipients of the exposure. In such situations, estimates may or may not be based on the assumptions of linearity and a nonthreshold dose. In any case, the assumptions will be stated explicitly in any EPA radiation protection actions.

"The linear hypothesis by itself precludes the development of acceptable levels of risk based solely on health considerations. Therefore, in establishing radiation protection positions, the Agency will weigh not only the health impact, but also social, economic, and other considerations associated with the activities addressed."

Within the context of the overall policy statement reprinted above, EPA uses primarily the recommendations of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) *(11.1)* as expressed in their November 1972 report to arrive at dose-to-health risk conversion factors. Besides the concept of linearity expressed in the policy statement, it is further assumed that health effects that have been observed at dose rates much greater than those represented in this report are indicative of radiation effects at lower dose rates. Any difference in biological recovery from precarcinogenic radiation damage due to low dose rates is neglected in the BEIR health risk estimates. On the other hand, in some cases, the BEIR risk estimates are based on relatively large doses where cell killing may have reduced the probability of delayed effects being observed and hence, underestimate the effects at low doses. The dose-risk conversion factors that EPA has adopted from the BEIR report are neither upper nor lower estimates of risk, but are computed on the same basis as the risk characterized as "the most likely estimate" in the BEIR report, that is they are averages of the two risk models considered in the BEIR report; relative and absolute risk.

One must caution against interpreting the product of dose and risk conversion factor as a prediction of actual number of effects to be sought out in the real world. The dose conversion factors (from concentration to dose) and the risk conversion factors (dose to effects) yield estimates of the actual dose and effects which have a considerable range. For example, the BEIR Committee has made a determination, based on their evaluation of the increase of the ambient cancer mortality per rem, that ranges from 100 to 450 deaths per million persons per rem during a 30-year followup period. EPA has chosen average values to be used for various dose to health effect conversion factors. When new information becomes available these factors will be revised.

Dose-risk Conversion Factors

1. Total body dose-risk

The BEIR Report calculates the excess cancer mortality risk (including leukemia mortality) from whole body radiation by two quite different models. The absolute risk model[1] predicts about 100 cancer deaths per 10^6 person-rem while the relative risk model[2] predicts between 160 and 450. An average cancer mortality of 300 annually per 10^6 person-rem would seem to be an appropriate mean for the relative risk model. The average of the absolute and relative risk models is about 200 per 10^6 person-rem. Cancer mortality is not a measure of the total cancer risk, which the committee states is about twice the risk of fatal cancer.

Estimated cancer risk from total body irradiation

Cancer mortality = 200 deaths per year for 10^6 person-rem annual exposure. Total cancers = 400 cancers per year for 10^6 person-rem annual exposure to the total body.

2. Gonadal dose-risk

The range of the risk estimates for genetic effects set forth in the BEIR report is so large that such risks are better considered on a relative basis for different exposure situations than in terms of absolute numbers. The range of uncertainty for the "doubling dose" (the dose required to double the natural mutation rate) is 10-fold (from 20 to 200 rad); and because of the additional uncertainties in (1) the fraction of presently observed genetic effects due to background radiation, and (2) the fraction of deleterious mutations eliminated per generation, the overall uncertainty is about a factor of 25. The total number of individuals showing genetic effects such as congenital anomalies, constitutional and degenerative diseases, etc., is estimated at somewhere between 1,800 and 45,000 per generation per rad of continuous exposure at equilibrium; i.e., 60-1,500 per year if a 30-year generation time is assumed. This equilibrium level of effect will not be reached until many generations of exposure have past; the risk to the first generation postexposure is about a factor of 5 less than the equilibrium level.

The authors of the BEIR report reject the notion of "genetic death" as a measure of radiation risk. Their risk analysis is in terms of early and delayed effects observed post partum and not early abortion, still births or reduced fecundity. Because of the seriousness of some of the genetic effects considered here, e.g., mongolism, the emotional and financial stress would be somewhat similar to death impact. Indeed, 10 percent of the effects described are those which lead directly to infant or childhood mortality (fetal mortality is excluded). For some purposes, this class of genetic effects is considered on the same basis as mortality.

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[1] Absolute risk estimates are based on the reported number of excess cancer deaths per rad that had been observed in exposed population groups, e.g., Hiroshima, Nagasaki, etc.

[2] Relative risk estimates are based on the percentage increase per rem in the ambient cancer mortality.

Estimated serious genetic risk from continuous gonadal irradiation

Total risk = 200 effects per year for 10^6 person-rem annual exposure in the U.S. population with a 50-year generation time.

3. Lung dose-risk

Due to the insufficient data for the younger age groups, estimates of lung cancer mortality in the BEIR report are only for that fraction of the population of age 10 or more. For the risk estimate made below, it is assumed that the fractional abundance for lung tumors is the same for those irradiated at less than 10 years of age as it is for those over 10. On an absolute risk basis, lung cancer mortality in a population would be about 18 deaths per annum per 10^6 persons irradiated continuously at a dose rate of 1 rem per year. This is a minimum value. The BEIR report states that the absolute risk estimates may be too low because observation times for exposed persons are still relatively short compared to the long latency period for lung cancer and indeed the NAS committee report on "Health Effects of Alpha-Emitting Particles in the Respiratory Tract" *(11.2)* indicates that the current (1976) estimate is twice that made in 1972. Furthermore, lung cancer risks calculated on the basis of the geometric mean of the relative risk is 3.4 times larger than the estimated absolute risk. Therefore, an average of mean relative and absolute risk estimates is given in the following dose-risk estimate.

Estimated lung cancer risk from continuous lung irradiation

Excess lung cancer mortality = 40 deaths per year for 10^6 person-rem annual exposure.

4. Thyroid dose-risk

The insult from radioiodines is important only for the thyroid. The dose to other organs is over an order of magnitude less. Two health effects follow high level exposures of thyroid tissue to ionizing radiation: benign neoplasms and thyroid cancer. Though the former is a more common radiation effect, only the risk from cancer is considered here.

While children are particularly sensitive to radiation damage to their thyroid glands, thyroid cancer is a serious but usually not a deadly disease particularly for persons in younger age groups. Mortality may approach 20 percent in persons well past middle age. It is not presently known if the radiation-induced cancers which are more frequent for persons irradiated early in life will follow the same patterns of late mortality.

The BEIR report provides risk estimates only for morbidity (not mortality) and only for persons under 9 years of age, i.e., 1.6-9.3 cancers per 10^6 person-rem years. Additional follow-up on external irradiation cases, suggests a thyroid malignancy rate of $4/y/10^6$ person-rem (range 1.5-16) and perhaps age at irradiation is not as important as originally thought *(11.3)*.

Since information in the BEIR report is not sufficient in itself to estimate the cancer incidence from continuous exposure, tentative risk estimates for this study are also based on information in other references *(11.4-11.7)* as well as the mean of the BEIR Committee's various estimates of incidence per rem. Infants and fetuses are probably the most sensitive group. By weighting the age group sensitivity and using population percentages for the age groups, a population age-weighted value was obtained. This estimate will be changed to reflect new followup data when it is reported in the published literature.

Estimated thyroid cancer risk

Thyroid cancer risk = 60 excess thyroid cancers per 10^6 thyroid-rems.

It is unlikely that the mortality from thyroid cancer would be more than 5-20 percent of its rate of incidence. As for other radiation effects, a true measure of the risk from thyroid cancers could be life shortening, but insufficient mortality data prevents such an approach.

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Chapter 12 - Nonionizing Electromagnetic Radiation

As its name implies, nonionizing electromagnetic radiation does not produce ionized particles when it is absorbed by the material of interest. Absorbed energy is converted to electronic excitation and to molecular vibration and rotation. The ionization potentials of the principal components of living tissue (water, and atomic oxygen, hydrogen, nitrogen, and carbon) are between 11 and 15 electron volts (eV). Michaelson *(12.1)* considers 12 eV to be the lower limit for ionization in biological systems, while noting that some weak hydrogen bonds in macromolecules may have lower ionization potentials. As a point of reference, an ultraviolet wavelength of 180 nanometers corresponds to an energy of about 7 eV. Thus, for practical purposes, the nonionizing part of the electromagnetic spectrum includes the ultraviolet, visible, infrared, radiofrequency and lower frequency regions. The electromagnetic fields from electric power distribution at 50 and 60 Hz are included, although these fields are not radiative in nature.

Because of the increase in the number and power of sources in the radiofrequency range since 1940, recent interest has focused on nonionizing electromagnetic radiation at frequencies below 300 GHz or photon energies less than 1.24×10^{-3} eV. The voluntary American National Standards Institute (ANSI) *(12.2)* exposure standard and the OSHA *(12.3)* occupational exposure standard cover the frequency range from 10 MHz to 100 GHz; the Bureau of Radiological Health (BRH) *(12.4)* microwave oven performance standard and the proposed BRH *(12.5)* diathermy performance standard are for frequencies from 890 MHz to 6 GHz and 890 MHz to 22.25 GHz, respectively. Though there may be limited exposure problems associated with the use of lasers and some noncoherent light sources, at the present time we are not aware of manmade sources of nonionizing electromagnetic radiation operating above 300 GHz which would produce significant environmental levels. Therefore, this discussion is restricted to frequencies below 300 GHz.

Sources of data

There are two types of data base which are pertinent to analyzing environmental levels of nonionizing electromagnetic radiation at frequencies below 300 GHz. The first of these consists of computer files of source location and characteristics that permit the calculation of expected exposure levels if an appropriate model and sufficient source parameters are available. The second type of data base consists of reports on studies of specific sources and the ambient environment. Until recently, only limited data have been available on the ambient environment.

The Office of Telecommunications Policy (OTP) assigns operating frequencies to government users of the electromagnetic spectrum and the Federal Communications Commission (FCC) assigns frequencies to nongovernment users. The most extensive inventory of sources of nonionizing radiation in the United States is maintained at the Electromagnetic Compatibility Analysis Center (ECAC), Department of Defense, Annapolis, Md. The ECAC Environmental File contains records of government and nongovernment communications-electronics equipment. Information in the records includes the operational characteristics of the equipment, its location, and administrative information, such as who is operating it. There are four subfiles of the Environmental File. These are the E-file, the Interdepartment Radio Advisory Committee (IRAC) File, including frequency authorizations of all U.S. government agencies, the AT&T File, containing the common carrier records, and the FCC File, with all the FCC-licensed equipment records.

These equipment records are fairly complete with regard to location, identification, and major characteristics. However, characteristics which are necessary for sophisticated models are often incomplete or lacking, so that only simple, approximate models can be used. This type of information is probably most useful in providing a method for sorting and ranking potential problem areas which can be studied later in more detail.

EPA has measured the radiation levels from a number of specific source types. These include satellite communications systems, acquisition and tracking radars, air traffic control radars, weather radars, FM radio transmitters, police radar units, and microwave ovens. An analytical model for predicting levels from sources having parabolic antennas has been developed and compared to other methods and measured data. Electric field profiles for 345-, 500-, and 765-kV overhead power transmission lines have been determined, and a magnetic field profile has been measured for a 500 kV line.

Techniques and instrumentation are available for the analysis of fields from most high-power sources. Methods for calculating power densities have been given by Mumford *(12.6)* and Tell *(12.7)*. Analysis of broadcast radiation sources has been given by Tell and Nelson *(12.8)*, and Tell and Janes *(12.9)*. Satellite communications earth terminals have been analyzed by Hankin *(12.10)*. Air traffic control radar's radiation levels have been measured by Tell and Nelson *(12.11)*, and airborne radars, by Tell and Nelson *(12.12)* and Tell, Hankin, and Janes *(12.13)*. The overall impact of high-power sources based upon measurements and theoretical analyses has been discussed by Hankin, et al. *(12.14, 12.15)*. The radiation levels on and near a high-power FM radio transmitter tower have been reported by Tell *(12.16)*. Hankin *(12.17)* has described the radiation characteristics of police traffic radars. Field strength measurements of microwave oven leakage at 915 MHz has been described by Tell *(12.18)*.

The highest power sources are satellite communications stations and large radars. Both of these source classes use very directive antennas to achieve extremely high effective radiated powers. Thus, the probability of being illuminated at any given time by the primary beam of one of these sources is quite small. Many of these sources are remotely located and almost all are surrounded by an exclusion area which further limits the probability of exposure. Site surveys are done for many sources to delineate operational procedures which will prevent the inadvertent exposure of occupied areas. Some sources are mechanically or electrically equipped to limit the pointing directions of antennas or to reduce or shut off power when occupied areas are scanned. The rotational feature of many radars further reduces the exposure levels. Nevertheless, a careful examination of the siting and operation of high-powered sources is required to assure they are installed and operated safely. When factors such as number of sources, number of persons potentially exposed, and general operating characteristics and procedures are considered, broadcast transmitters are the most environmentally significant category.

High voltage transmission lines

Private citizens, public interest groups, and State agencies have expressed concern about the potential adverse effects of electric power at extra-high voltages (EHV), i.e., voltages at or above 345 kilovolts. Because of these concerns, EPA published a notice in the Federal Register in 1975, requesting data and information on health and environmental effects of EHV power transmission *(12.19)*. Over 50 replies totaling over 6,000 pages were received *(12.20)*. In 1976, a request for proposals to evaluate and summarize the information received was prepared and made public. The proposals received in response have been evaluated in preparation for the award of a contract. Contractual arrangements will be made in 1977, and the desired evaluation and summary should be available by the end of the year.

The Agency is represented on the Interagency Advisory Committee on Electric Field Effects from High Voltage Lines, chaired by ERDA. The committee's objective is to coordinate federally sponsored efforts relating to the environmental effects of electric fields from high voltage transmission lines.

The Environmental Protection Agency will decide on the need for guidance or standards relative to discharge currents (electric shock potential), based on the contracted review of the material submitted to EPA and the results of the activities of the Interagency Advisory Committee on Electric Field Effects from High Voltage Lines.

Ambient environmental levels

For the purposes of this discussion, we will broadly define the general ambient electromagnetic environment to be the electromagnetic field in the frequency band from 0 to 300 GHz. It results from the superposition of the field from all sources contributing to the field at the point of interest. In practice this means all sources which produce fields greater than the noise level of the detection system will contribute to the measured level. The actual level may be high or low depending on the distribution of contributing sources, but in most cases, should be relatively low when compared to levels in the main beam of powerful sources. Actual measurements will, for the most part, cover more restricted frequency ranges than those considered in the definition. Two types of instruments are used, those which preserve frequency information and those which integrate across a band of frequencies. Only a limited amount of data is available on general ambient environments. A great deal of data has been collected in so-called noise studies such as that of Toler *(12.21)*. However, these studies ignore intentional signals and are not useful in estimating total exposure although they help determine signal amplitude requirements for communication and serve as an indicator of the increase in the use of the electromagnetic spectrum.

In 1969, White Electromagnetics and the Public Health Service measured peak power densities in the Washington, D.C. area *(12.11,12.23)*. Radiation levels were monitored over the frequency range from 20 Hz to 10 GHz at 10 sites within a 25-mile radius of the city. The highest levels measured (approximately 10 $\mu W/cm^2$) originated primarily from AM broadcast towers and airport radar installations. The accuracy of the measurements was estimated to be within 15 decibels (dB) in the first paper and at ± 10 dB in the second (dB is a logarithmic unit of power and 10 dB corresponds to one order of magnitude, i.e., a factor of 10). A similar study over a more restricted frequency range was conducted in Las Vegas in 1970 by Envall, Peterson, and Stewart *(12.24)*. The maximum observed power density over the frequency range from 54 to 220 MHz was 0.8 $\mu W/cm^2$. Ruggera *(12.25)* studied the changes in electric field strengths within a hospital before and after the installation of a new transmitting tower 3,200 feet from the hospital. Measurements were made in the frequency range from 54 MHz to 656 MHz and the maximum total root mean square (rms) field strength was about 2 V/m which corresponds to a far-field power density of about 1 $\mu W/cm^2$.

As part of a program to determine the need for standards to control environmental radiofrequency exposure, the U.S. Environmental Protection Agency (EPA) began measuring levels of radiofrequency radiation in urban areas in October 1975. Measurements are made principally in urban areas because sources are concentrated in and around regions of high population density *(12.26,12.27)*. Measurements have shown that the principal sources of environmental radiofrequency radiation are in the broadcast bands *(12.28)* with other bands making only minor contributions to the general environmental levels. Therefore, data are collected in the seven frequency bands shown in table 12-1.

The measurement system consists of seven antennas, listed in table 12-1, a scanning spectrum analyzer, and a minicomputer. The equipment is installed in a van equipped with gasoline-powered electrical generators. Antennas are mounted sequentially on a pneumatically operated, telescoping mast and elevated 6.4 meters above ground level. After a predetermined number of scans through the desired frequency range, the data are corrected for antenna response and both the average root-mean-square values of the electric field strength and the power density obtained by integration of the squared field strength values are computed. The calculated values are displayed on the computer's cathode ray tube, copied onto thermally sensitive paper, and stored in the computer's memory. The measurement system, antenna calibration, and the analysis of system error are described in detail in reference *12.29*. Examples of typical spectra can be found in references *12.9,12.29*, and *12.30*.

Measurements of environmental radiofrequency field strengths have been made at 72 sites located in Atlanta, Boston, Miami, or Philadelphia. The percent of sites having values equal to or less than a given total power density in the frequency range from 54- to 900-MHz are plotted against the logarithm of the power density on probability paper in figure 12-1. Distributions for the land mobile bands, the low VHF-TV band, and the FM band are also shown. The power density values from the 0-2 MHz band are not included in this analysis. The FM band contributes the most to environmental radiofrequency exposure between 54- and 900-MHz. Within this range of frequencies each of the three TV bands contributes about equally. The land mobile bands make an almost negligible contribution to the total power density and less active bands would make even smaller contributions. The maximum power density at any site summed over all bands was 2.5 $\mu W/cm^2$. Four sites or about 6 percent fell in the range of 1 to 2.5 $\mu W/cm^2$ so that some of the population is potentially exposed to values in excess of 1 $\mu W/cm^2$.

Population exposure

An estimator of population exposure must combine information on the distribution of radiofrequency levels with the distribution of population to provide numbers of people exposed at various levels. The population data base which was used here has been described elsewhere *(12.31)*, but briefly, it consists of the population count for each of

Table 12-1. Antennas used for environmental radiofrequency measurements

Frequency (MHz)	Use	Antenna
0-2	VLF communications and AM standard broadcast	Active vertical monopole
54-88	Low VHF television broadcast	Two horizontal orthogonal dipoles
88-108	FM broadcast	Three orthogonal dipoles
150-162	VHF land mobile	Vertical coaxial dipole
174-216	High VHF television broadcast	Two horizontal orthogonal dipoles
450-470	UHF land mobile	Vertical coaxial dipole
470-806	UHF television broadcast	Horizontal polarized directional log periodic

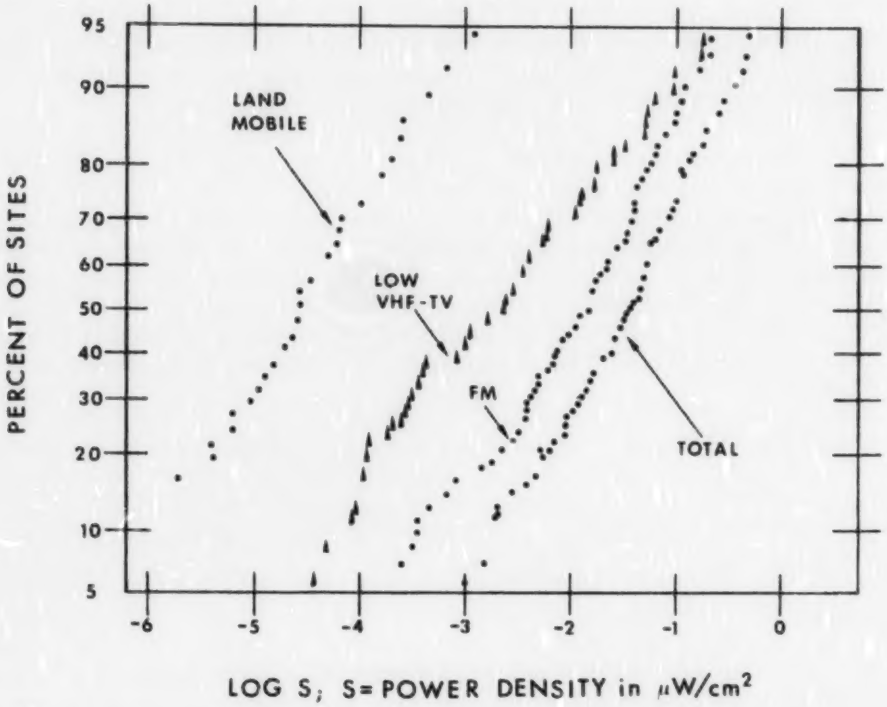

Figure 12-1. Percent of sites having values equal to or less than a given total power density in the frequency range from 54 to 900 MHz

250,000 census enumeration districts (CED) in the United States along with the geographic coordinates of the approximate population centroid for the CED. The population of an area is considered to be concentrated at a set of discrete points. The total power density from all sources at each of these discrete points is determined and the population exposed at the various levels is summed.

The model for determining the radiofrequency fields is based on data collected with the measurement system described above. The measured data from each source were observed to generally fall on a parabola when plotted as log (power density) versus log (distance). Furthermore, the shape of this parabola was approximately the same for all sources, regardless of source parameters, differing from source to source primarily by an additive constant. Therefore, an empirical expression for the field strength, E, in dB above 1 μV/m, as a function of log D (D = distance in miles), was chosen:

$$E = -10 (\log D)^2 - 20 \log D + C$$

where C is a source specific constant. To determine the field strength at any point (e.g., at a CED centroid) the three measurement sites nearest the point of interest are determined, and from the measured data at these three points, a value of the constant C for each source is determined. Substitution of the distance from the source to the point into the expression for E yields the required field strength estimate for that source. The individual source contributions can be appropriately summed to get the total exposure.

This approach was applied to each CED centroid in the four metropolitan areas where measurements had been made *(12.32)*. The population for each CED was assigned the exposure determined for its centroid location. This information was sorted according to exposure ranges, and the results are presented in figure 12-2 which shows the fraction of the population in the four metropolitan areas (total population = 8.3 million) exposed to various levels. The median power density is 0.014 μW/cm². Less than one percent of the population is exposed to values greater than 1 μW/cm².

This model for population exposure does not account for complications such as daily movements of the population within an area, exposures at heights greater than 6 meters where exposures can be higher due to nonuniform antenna radiation patterns, for any attenuation effects of typical buildings, or for times when sources are not transmitting. The results are simply the population residing in areas where an unobstructed measurement 6 meters above ground would result in the indicated values.

In addition to the general environmental measurements, data were collected at a few selected sites in tall buildings which were located

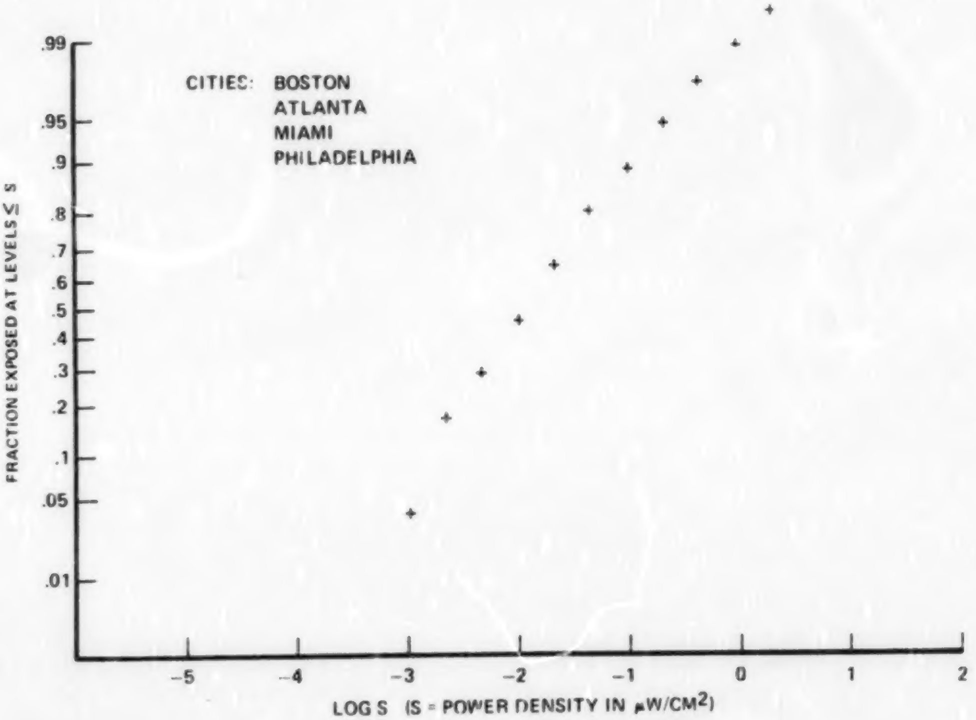

Figure 12-2. Fraction of population exposed as a function of power density

near transmitters in Chicago, Miami, and New York. The upper floors of some buildings may be higher than a transmitter on a neighboring building, and thereby be exposed to the main beam of the transmitter.

These building measurements were performed using a tuned half-wave dipole connected to a portable spectrum analyzer. Signal amplitudes displayed on the spectrum analyzer were photographed and the values obtained were corrected for antenna factors. The tuned dipoles were previously calibrated against a set of National Bureau of Standards calibrated dipoles *(12.29)*. The resulting field strength, E (volts per meter), may be converted to equivalent far-field power density, S ($\mu W/cm^2$), through the relation

$$S\ (\mu W/cm^2) = \frac{100\ [E(V/m)]^2}{377}$$

The measurements show that power density levels in some areas of the upper floors of tall buildings can be much higher than measurements made at ground level. At windows facing transmitters, with blinds raised, the maximum levels observed in selected buildings in New York, Miami, and Chicago were 32, 97, and 66 $\mu W/cm^2$ respectively, and consisted primarily of radiation from FM radio and UHF-TV transmitters. These levels should not be regarded as typical of tall buildings, or even typical of these selected buildings. Structural materials and window blinds can significantly reduce actual levels inside the buildings. These preliminary results will be further characterized in future studies.

Discussion

There is a large difference in the exposure standards of the United States and the U.S.S.R., those of the latter being much more restrictive. The level for unlimited occupational exposure in the Soviet Union is 10 $\mu W/cm^2$, and the proposed environmental level is 1 $\mu W/cm^2$. Controversy continues over the validity of the Soviet standard. The Soviet standard was adopted in Poland in 1961, pending an independent evaluation. In 1972, the Polish standard was revised and the occupational level was set at 200 $\mu W/cm^2$, and the environmental limit was set at 10 $\mu W/cm^2$ *(12.33)*.

Research is now underway in this country and elsewhere to determine and assess any possible biological effect of long-term exposure to low levels of nonionizing radiation and to examine the validity of the present occupational exposure standard of 10 mW/cm^2. Also of concern are the effects of high peak power, low average power, pulsed radiation and the questions of the need for and how to develop standards for the frequency range below 10 MHz where there is currently no exposure standard. Four types of overlapping exposure can be distinguished: (1) exposure in the general environment to intentional signals from the broadcast services, radars, leakage radiation, and other sources, (2) occupational exposures, (3) exposure to leakage radiation from consumer devices such as microwave ovens, and (4) intentional medical exposures. Occupational exposure is subject to control by OSHA. Intentional medical exposure is given at the discretion of a physician, but a performance standard is now being developed by the Food and Drug Administration for leakage and scatter from microwave diathermy units. There is no direct control of environmental exposure from microwave diathermy apparatus. Indirect controls of environmental exposures are the limitation put on effective radiated power by the FCC, their requirement for posting areas about domestic satellite stations where levels exceed 10 mW/cm^2, and the operational procedures employed in using both government and nongovernment sources. Also, any telecommunications system planned for purchase by the government, as a condition for spectrum approval, is reviewed by IRAC-OTP to assess among other factors whether levels in excess of 10 mW/cm^2 will occur and whether operational measures have been provided to insure that people are not exposed above this level.

Two types of environmental exposure can be distinguished. One is the relatively high radiation level from high power sources such as some radars and satellite communications stations where the power density in the useful beam can exceed that thought to be safe for human occupancy even outside the boundary of the facility *(12.15)*. The problems associated with such sources are recognized and instrumentation and techniques for analyzing exposure from them are available. The other type of environmental exposure arises from the superposition of the fields from many sources at different frequencies. This exposure may be high or low depending on the location and types of sources contributing to the exposure and includes the specific source problem as a special case. Nonionizing environmental radiation data are needed to interpret the results of current biological effects research and establish the predominant frequencies in the environment so that future research for the validation of standards can be appropriately directed.

Summary

General environmental surveys have been completed in seven cities in the Eastern United States. The data and population exposure implications for the first four of these are presented here and analysis is continuing on the other three. The measurement program will now continue in several cities in the Western United States.

The results to date suggest that probably 99 percent of the urban population is exposed at levels which would be permitted even under the restrictive proposed Soviet standard of 1 $\mu W/cm^2$. The general environmental data cannot be used to estimate the levels to which the remaining 1 percent of the population is exposed. Further information will require a detailed analysis of specific sources and a detailed knowledge of the locations of the persons exposed to such sources.

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Glossary

Absorbed dose (*D*) - The energy imparted to a unit mass of matter by ionizing radiation. The unit of absorbed dose is the rad. One rad equals 100 ergs per gram (See rad).

Accelerator - A device for increasing the kinetic energy of charged elementary particles, for example, electrons or protons, through the application of electrical and/or magnetic forces.

AEC - U.S. Atomic Energy Commission - In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission, and the reactor development portion became part of the Energy Research and Development Administration.

Agreement States - Those States which, pursuant to Section 274 of the Atomic Energy Act of 1954, as amended, have entered into an agreement with the NRC for assumption of regulatory control of byproduct, source, and small quantities of special nuclear materials. Before approving an agreement State, NRC must determine that the State's radiation control program is compatible with NRC's regulatory program and is adequate to protect public health and safety.

Body burden - The amount of radioactive material present in the body of a man or an animal.

Boiling water reactor (BWR) - A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.

By-product material - Any radioactive material (except source material or fissionable material) obtained during the production or use of source material or fissionable material. It includes fission products and many other radioisotopes produced in nuclear reactors.

Cosmic radiation - Radiation of many sorts but mostly atomic nuclei (protons) with very high energies, originating outside the earth's atmosphere. Cosmic radiation is part of the natural background radiation. Some cosmic rays are more energetic than any manmade forms of radiation.

Curie (Ci) - The special unit of activity. One curie equals 3.7×10^{10} nuclear transformations per second.

Daughter - A nuclide formed by the radioactive decay of another nuclide, which in this context is called the parent.

Decommissioning - The process of removing a facility or area from operation and decontaminating and/or disposing of it or placing it in a condition of standby with appropriate controls and safeguards.

Decontamination - The selective removal of radioactive material from a surface or from within another material.

Diathermy - The generation of heat in tissues for medical or surgical purposes by electric currents.

Disposal - The planned release or placement of waste in a manner that precludes recovery.

Dose - A general term denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. If unqualified, it refers to absorbed dose.

Dose equivalent (*H*) - A quantity used in radiation protection. It expresses all radiations on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors (The unit of dose equivalent is the rem).

Dose rate - Absorbed dose delivered per unit time.

$8.00 reserves - Ore that can be mined and processed for $8.00 a pound.

Electron volt (eV) - A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. Larger multiples of the electron volt are frequently used: KeV for thousand or kilo electron volts: MeV for million or mega electron volts ($1 \text{ eV} = 1.6 \times 10^{-12}$ erg).

Energy Research and Development Administration (ERDA) - In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission and the reactor development portion became part of the Energy Research and Development Administration.

Exposure - A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

External radiation - Radiation from a source outside the body.

Flux density (neutron) - A term used to express the number of neutrons entering a sphere of unit cross-sectional area in unit time. For neutrons of given energy, the product of neutron density and speed.

Frequency - Number of cycles, revolutions, or vibrations completed in a unit of time (See Hertz).

Fuel cycle - The complete series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication into new fuel elements, and management of radioactive waste.

Genetically significant dose (GSD) - The gonadal dose which, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses that are actually received. It is not a forecast of predictable adverse effects on any individual person or his/her unborn children.

Gonad - A gamete-producing organ in animals; testis or ovary.

Half-life - Time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

Hertz - Unit of frequency equal to one cycle per second, generally applied to nonionizing radiation.

High-level liquid waste - The aqueous waste resulting from the operation of the first-cycle extraction system, equivalent concentrated wastes from a process not using solvent extraction, in a facility for processing irradiated reactor fuels. This is the legal definition used by ERDA; another definition used at the ERDA Hanford Reservation for its waste, is: fluid materials, disposed of by storage in underground tanks that are contaminated by greater than 100 microcuries per milliliter of mixed fission products or more than 2 microcuries per milliliter of cesium-137, strontium-90, or long-lived alpha emitters.

High temperature gas-cooled reactor (HTGR) - A reactor in which the temperature is great enough to permit generation of mechanical power at good efficiency using gas as the coolant.

ICRP - International Commission on Radiological Protection.

Intermediate-level liquid waste - Fluid materials, disposed as a result of Hanford operations, which contain from 5 x 10^5 microcuries per milliliter to 100 microcuries per milliliter of mixed fission products, including less than 2 microcuries per milliliter of cesium-137, strontium-90, or long-lived alpha emitters.

Internal radiation - Radiation from a source within the body as a result of deposition of radionuclides in body tissues by ingestion, inhalation, or implantation.

Ionization - The process by which a neutral atom or molecule acquires a positive or negative charge.

Isotopes - Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore, in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

Licensed material - Source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or special license issued by the U.S. Energy Research and Development Administration or a State.

Linear accelerators - A device for accelerating charged particles. It employs alternate electrodes and gaps arranged in a straight line, so proportioned that when potentials are varied in the proper amplitude and frequency, particles passing through the waveguide receive successive increments of energy.

Low-level liquid waste - Fluid materials that are contaminated by less than 5 x 10^{-5} microcuries per milliliter of mixed fission products.

Man-rem - The product of the average individual dose in a population times the number of individuals in the population. Syn: Person-rem.

Maximum permissible dose equivalent (MPD) - The greatest dose equivalent that a person or specified part of the body shall be allowed to receive in a given period of time.

Millfeed - The ore and other material introduced into the milling process.

Millirem (mrem) - One-thousandth of a rem (See rem).

Muon - An elementary particle classed as a lepton, with 207 times the mass of an electron. It may have a single positive or negative charge.

NRC - U.S. Nuclear Regulatory Commission: In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission and the reactor development portion became part of the Energy Research and Development Administration.

Nuclide - A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N) and energy content; or alternatively, by the atomic number (Z), mass number A = (N + Z), and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time. Thus, nuclear isomers are separate nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

Permissible dose - The dose of radiation which may be received by an individual within a specified period with expectation of no significantly harmful result.

Person-rem - The product of the average individual dose in a population times the number of individuals in the population. Syn: man-rem.

Polarization - In electromagnetic waves, refers to the direction of the electric field vector.

Population dose - The sum of radiation doses of individuals and is expressed in units of person-rem (e.g. if 1,000 people each received a radiation dose of 1 rem, their population dose would be 1,000 person-rem).

Power density - The intensity of electromagnetic radiation power per unit area expressed as watts/cm^2.

Pressurized water reactor (PWR) - A power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

Quality factor (Q) - The linear-energy-transfer-dependent factor by which absorbed doses are multiplied to obtain (for radiation protection purposes) a quantity that expresses-on a common scale for all ionizing radiations-the effectiveness of the absorbed dose.

Rad (Acronyn for radiation absorbed dose) - The special unit of absorbed dose of ionizing radiation. A dose of one rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material (See absorbed dose).

Radioactive decay - Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

Radioisotope - A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

Radwaste - Waste materials that are contaminated with radioactive materials.

Rem - The special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor (Q), and the product of any other modifying factors (N) at the point of interest in tissue. ICRP has presently assigned a value of 1 for irradiations by external sources.

Roentgen (R) - The special unit of exposure. One roentgen equals 2.58 x 10^{-4} coulomb per kilogram of air (See exposure).

Skin dose (Radiology) - Absorbed dose at center of irradiation field on skin. It is the sum of the dose in air and scatter from body parts.

Skyshine - Radiation emitted through the roof of the shield (or unshielded roof) that scatters back to ground level due to its deviation by the atmosphere.

Solid wastes (Radioactive) - Either solid radioactive material or solid objects that contain radioactive material or bear radioactive surface contamination.

Source material - In the Code of Federal Regulations (CFR), any material except special nuclear material, which contains 0.05 percent or more of uranium, thorium, or any combination of the two.

Special nuclear material - In the Code of Federal Regulations (CFR), this term refers to plutonium-239, uranium-233, uranium containing more than the natural abundance of uranium-235, or any material artificially enriched in any of these substances.

SWU - Standard work units.

Transuranium - Nuclides having an atomic number greater than that of uranium (i.e., greater than 92).

Technologically enhanced natural radioactivity (TENR) - Naturally radioactive nuclides whose relationship to the location of persons has been altered through man's activities such as by the activities of mining, tunneling, development of underground caverns, development of wells, and travel in space or at high altitudes.

Terrestrial radiation - Radiation emitted by naturally occurring radionuclides such as potassium-40; the natural decay chains uranium-238, uranium-235, or thorium-232; or from cosmic-ray induced radionuclides in the soil.

Type A and Type B quantities - Legally established maximum amounts of radioactive materials which can be contained in Type A and Type B packages, respectively. Precise definitions are listed in 49 CFR 173.389(1), however, basically the radionuclides are divided into seven groups according to their radiotoxicity and relative potential hazard in transportation. Each of these groups then has a maximum amount assigned depending on the type of package to be used to ship it.

Type A packaging - Containers designed to maintain their integrity, i.e., not allow any radioactive material to be released and to keep the shielding properties intact, under normal transportation conditions. The test conditions which must be met are defined in 49 CFR 173.398b and include heat, cold, reduced air pressure, vibration, water spray endurance, free drop, penetration, and compression standards.

Type B packaging - Containers designed to meet the standards established for hypothetical transportation accident conditions, as well as meeting the Type A packaging standards, without reducing the effectiveness of the shielding or allowing releases in excess of those enumerated in 49 CFR 173.398c(1). The standards to be met by Type B packages, in addition to the Type A standards, are defined in 49 CFR 173.398c(2) and include puncture, thermal, water immersion, and higher free drop tests.

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation.

Volt (V) - The unit of electromotive force (1 volt = 1 watt/1 ampere).

Whole body dose - The radiation dose to the entire body.

International numerical multiple and submultiple prefixes

Multiples and submultiples	Prefixes	Symbols
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

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